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Our October 2016 issue will be published on Thursday 01 September 2016, see page 72 for details.

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Assembled Order Code: AS3149E - ***£38.95***
Assembled with ZIF socket Order Code: AS3149EZIF - ~~**£74.96**~~ ***£48.95***

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This tutorial project board is all you need to take your first steps into Microchip PIC programming using a PIC16F882 (included). Later you can use it for more advanced programming. It programs all the devices a Microchip PICKIT2® can! You can use the free Microchip tools for the PICKit2™ and the MPLAB® IDE environment.
Order Code: EDU10 - ***£46.74***

ATMEL 89xxxx Programmer

Uses serial port and any standard terminal comms program. 4 LED's display the status. ZIF sockets not included. 16Vdc.
Kit Order Code: 3123KT - ~~**£32.95**~~ ***£21.95***
Assembled ZIF: AS3123ZIF- ~~**£48.96**~~ ***£37.96***

Introduction to PIC Programming

Go from complete beginner to burning a PIC and writing code in no time! Includes 49 page step-by-step PDF Tutorial Manual + Programming Hardware (with LED test section) + Windows Software (Program, Read, Verify & Erase) + a rewritable PIC16F84A. 4 detailed examples provided for you to learn from. PC parallel port. 12Vdc.
Kit Order Code: 3081KT - ***£17.95***
Assembled Order Code: AS3081 - ***£24.95***

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Versatile, low cost, PICKit™2 Development Programmer. Programs all the devices a Microchip PICKIT2 programmer can. Onboard sockets & ICSP header.
Assembled Order Code: VM203 - ***£39.54***

PIC Programmer & Experimenter Board

PIC Programmer & Experimenter Board with test buttons and LED indicators to carry out educational experiments such as the supplied programming examples. Includes a 16F627 Flash Microcontroller that can be reprogrammed up to 1000 times. Software to compile and program your source code is included. Supply: 12-15Vdc.
Kit Order Code: K8048 - ~~***£29.58***~~ ***£21.54***
Assembled Order Code: VM111 - ***£38.88***

Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £10.68

USB Experiment Interface Board

Updated Version! 5 digital inputs, 8 digital outputs plus two analogue inputs and two analogue outputs. 8 bit resolution. DLL.
Kit Order Code: K8055N - ~~***£39.95***~~ ***£22.74***
Assembled Order Code: VM110N - ***£39.95***

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State-of-the-art high security. Momentary or latching relay outputs rated to switch up to 240Vac @ 10 Amps. Range up to 40m. 15 Tx's can be learnt by one Rx (kit includes one Tx but more available separately). Supply 9-15Vdc.
Kit Order Code: 8157KT - ***£44.95***
Assembled Order Code: AS8157 - ***£49.96***

Computer Temperature Data Logger

Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS1820 sensor.
Kit Order Code: 3145KT - ~~***£19.95***~~ ***£16.97***
Assembled Order Code: AS3145 - ***£22.97***
Additional DS1820 Sensors - ***£4.96 each***

8-Channel Ethernet Relay Card Module

Connect to your router with standard network cable. Operate the 8 relays or check the status of input from anywhere in world. Use almost any internet browser, even mobile devices. Email status reports, programmable timers, ...
Assembled Order Code: VM201 - ***£134.40***

Many items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix)

4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, Rings to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.
Kit Order Code: 3140KT - ***£79.95***
Assembled Order Code: AS3140 - ***£94.95***

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our new Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.
Kit Order Code: 3108KT - ***£74.95***
Assembled Order Code: AS3108 - ***£89.95***

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Kit Order Code: 3142KT - ~~***£64.96***~~ **£51.96**
Assembled Order Code: AS3142 - **£61.96**

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Assembled Order Code: AS3153 - ***£49.96***

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Kit Order Code: 8191KT - ~~***£29.95***~~ **£24.95**
Assembled Order Code: AS8191 - **£29.95**

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Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

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4 channel computer serial port temperature monitor and relay controller. Four inputs for Dallas DS18S20 or DS18B20 digital thermometer sensors (£3.95 each). Four 5A rated relay outputs are independent of sensor channels allowing flexibility to setup the linkage in any way you choose. Simple text string commands for reading temperature and relay control via RS232 using a comms program like Windows HyperTerminal or our free Windows application.
Kit Order Code: 3190KT - ~~**£84.95**~~ **£59.95**
Assembled Order Code: AS3190 - **£74.95**

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Assembled Order Code: AS3188 - **£31.97**

Bipolar Stepper Motor Chopper Driver

Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
Kit Order Code: 3187KT - ***£39.95***
Assembled Order Code: AS3187 - ***£49.96***

LCD Oscilloscope Kit

Build your own oscilloscope with LCD display. Learn how to read signals with this exciting new kit. See the electronic signals you learn about displayed on your own LCD oscilloscope. Despite the low cost, this oscilloscope has many features found on expensive units, like signal markers, frequency, dB, true RMS readouts and more...
Kit Order Code: EDU08 - ***£49.99***

Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

DC Motor Speed Controller (100V/7.5A)

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
Kit Order Code: 3067KT - ***£19.95***
Assembled Order Code: AS3067 - ***£27.95***

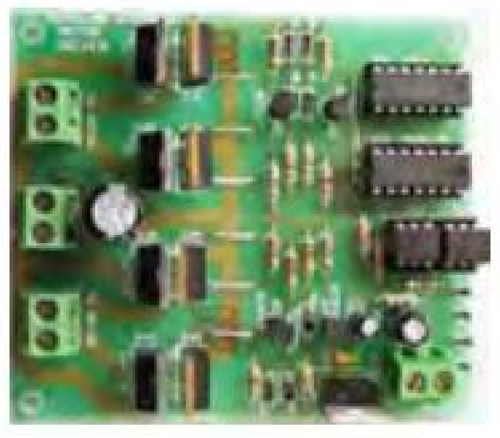
Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
Kit Order Code: 3166v2KT - ***£23.95***
Assembled Order Code: AS3166v2 - ***£33.95***

Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
Kit Order Code: 3179KT - ***£17.95***
Assembled Order Code: AS3179 - ***£24.95***

Computer Controlled Bi-Polar Stepper Motor Driver



Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
Kit Order Code: 3158KT - ~~***£24.95***~~ ***£21.20***
Assembled Order Code: AS3158 - ***£31.20***

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Reliable and simple to install project that allows you to adjust the speed of an electric drill or 230V AC single phase induction motor rated up to 600 Watts. Simply turn the potentiometer to adjust the motors RPM. PCB: 48x65mm. Not suitable for use with brushless AC motors.
Kit Order Code: 1074KT - ~~***£15.95***~~ ***£13.56***
Assembled Order Code: AS1074 - ***£21.56***

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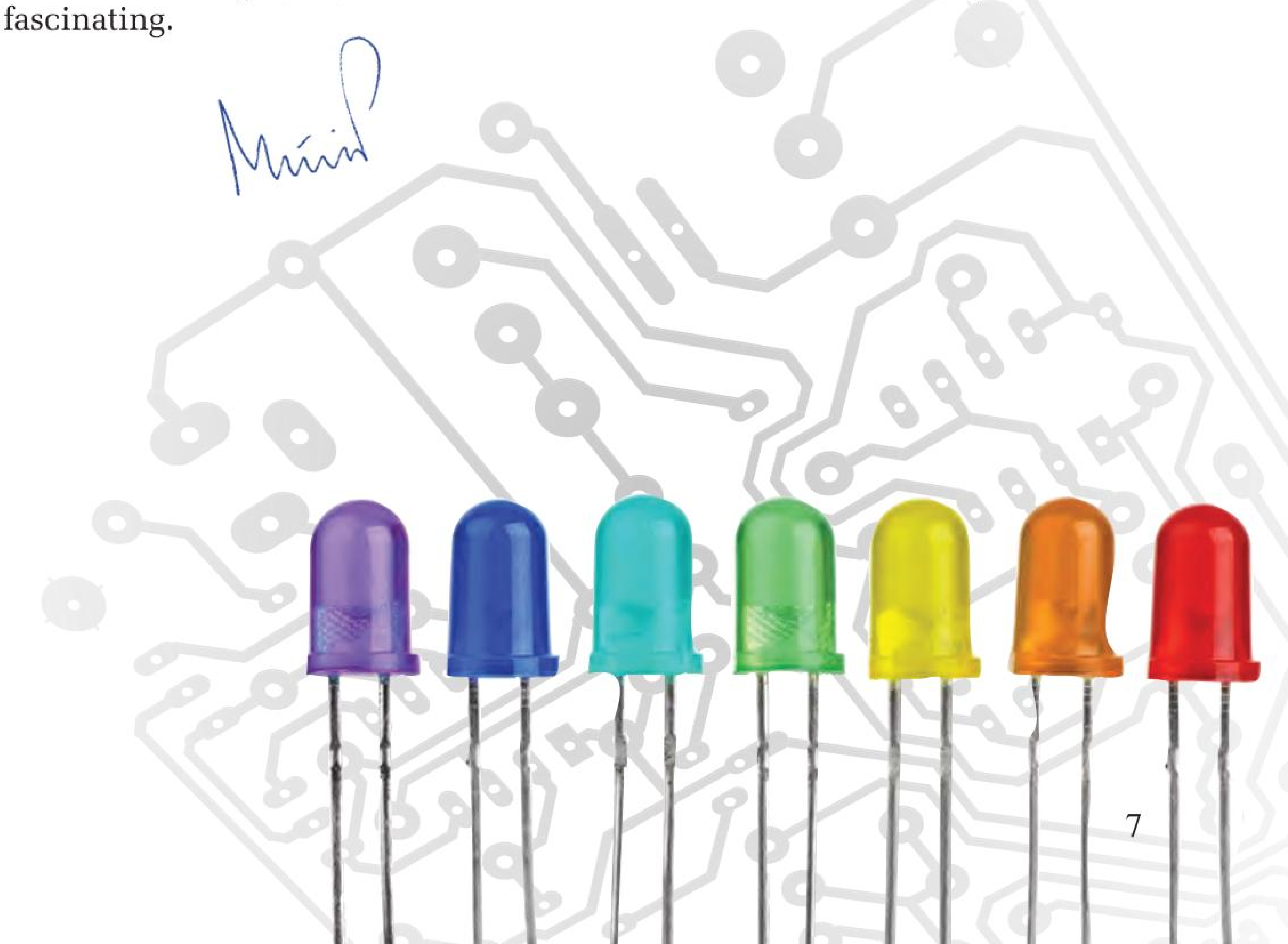
Rise of the sensors

Electronic sensor technology has been one of the great growth areas of the last dozen years – for example, consider inertial sensing. The miniaturisation of electromechanical systems such as gyroscopes and linear accelerometers to produce MEMS (microelectromechanical systems) has been at the heart of all those clever apps and games from Wii tennis to iPhone car racing, where a sensed twist of the screen simulates a steering wheel. Accurate gyroscopes and their electronics have been reduced in size from something the size of a shoe box costing tens of thousands of pounds to a grain of rice costing a few pounds. Optical sensors in digital cameras are another remarkable success story; increases in pixel count, dynamic range and low-light sensitivity, all coupled with plummeting prices have helped take digital photography to extraordinary levels of quality in a very few years. Although the rates of improvement of sensor technology may not be quite as rapid as for integrated circuits, I'm sure someone somewhere has produced a sensor version of Moore's law (**https://en.wikipedia.org/wiki/Moores_law**).

Recently, I have been reading about another sensor category that looks set to become affordable – long wavelength infrared sensors, or LWIR sensors for short. These sensors enable thermal images to be taken using similar techniques to optical sensor arrays, but working with much longer wavelengths of electromagnetic radiation, far beyond what the eye can register. All those multi-coloured images showing where buildings leaks heat were taken with this kind of thermal imaging equipment.

Such technology has historically been bulky, power hungry and expensive, but small and reasonably priced solutions are now available. Manufacturer Lepton offers a thermal camera sensor for a little over £100 with a resolution of 60 × 80 pixels. This may seem disappointing compared to the cheapest of optical sensors, but it is surprising how much information can be gleaned from such a 'lo-res' image. Doubtless in five years the cost will have plummeted and the resolution will have jumped as more and more applications for these fascinating sensors emerge.

Cheap and accurate LWIR sensors are just one of many sensing technologies set to build the interconnected revolution. Add that to the fast-growing Internet of Things (IoT) and the future for sensors looks absolutely fascinating.



NEWS

A roundup of the latest Everyday News
from the world of
electronics

The OLED heart of LG's TV technology – report *by Barry Fox*

Kodak may be dead in the consumer electronics water, but the fruits of Kodak's research live on – inside LG's latest OLED TVs. Although LG is notoriously reluctant to discuss the technology used in its OLED TVs, patents that Kodak filed ten years ago are now the springboard for new LG research and give a rare insight into the practical problems of mass-produced, affordable OLED TV screens that give bright pictures with stable colours, have acceptable life expectancy and do not consume excessive power.

Although reference to the deal has now been expunged from Kodak's web archive (**http://tinyurl.com/zh5cnau**) a research report from analysts IHS Technology (Q1 '15 *Quarterly OLED Materials Report*) revealed that in late 2009 Kodak sold a folio of patents on OLED technology to a joint venture between Idemitsu and LG, controlled (66/33) by LG. Kodak's folio included patents on what turned out to be the breakthrough idea of making colour TV screens much like LCD screens, from white OLED light emitters covered by red, green and blue filters, instead of from native red, green and blue OLED emitters.

LEDs... OLEDs... WOLEDs

According to IHS, making 55-inch TVs with white OLEDs – WOLEDs – and colour filters, instead of coloured OLED emitters, halves the cost of the materials used and gives a far higher yield rate (ratio of usable screens made, against faulty panels that have to be junked at the factory).

Kodak's US patent 7,531,959 claims the basic idea that 'the use of white OLEDs with colour filters provides a simpler manufacturing process than an OLED having separately patterned red, green, and blue emitters (and) this can result in higher throughput, increased yield, and cost savings.'

It's complicated

LG is now building on this basic idea. LG's US patent 9,263,502, frankly admits that so-called 'RGBW-type' screens, where red, green and blue filters are placed over White OLEDS, leads to a maze of Catch 22 compromises, such as a 'trade-off between the colour saturation, the driving current, the luminance and the lifetime of the OLED device'.

'The luminance of the OLED element is sacrificed as the white light from the OLED element passes through the colour filter elements' explains LG. 'In order to compensate the reduced luminance, higher current density is provided. Such increase in current density, however, leads to shortened lifetime of OLED elements and undesirable colour shifts as the display device age.'

Moreover 'the colour coordinates of the white light emitted from the OLED element can be distorted if the luminance of a certain emission layer becomes lower than the luminance of the other emission layers or the colour coordinate of a certain emission layer deviates from its initial preferred setting.'

'For example' says LG, 'if the luminance of an electroluminescent (EL) layer that emits blue light is lower than that of the other EL layers that emit other coloured light, the OLED element may not emit the white light with the ideal colour coordinate.'

'The driving voltage of the OLED element can be adjusted to correct such colour coordinate shift caused by a certain emission layer' says LG. 'However, not only does the algorithm for correcting colour coordinates require very complicated arithmetic operations, this method often involves increasing the current level at the white sub-pixel region as well as some of the other pixel regions in order to correct the overall colour saturation. This results in increased power consumption of the entire panel and reduced lifespan of the EL layer.'

'Using a low-power driving algorithm following the aforementioned calibration significantly complicates the overall operation' says LG. 'Even if such algorithms can be performed, other side effects may occur.'

Extra blue channel

LG's new idea follows from recognition of the fact that the blue filter is doing the most damage to the light output. The patented solution is a hybrid design, where the OLED separately generates white light and blue light. The white light is passed through red and green filters and the blue light travels direct; or the blue light may be purified by passing it through a blue filter.

Either way, says LG, 'the luminance of the blue light is substantially maintained' with 'improved emission efficiency and increased life-span' and 'the efficiency of the organic light-emitting element may be improved to increase the lifespan thereof and reduce power consumption.'

In response to my questions, LG has now confirmed: 'All LG OLED panels used in LG televisions are based on WRGB sub-pixel configuration (and) the organic layer of LG's 2016 OLED panels consist of four layers – two blue, one red and one yellow-green organic material layers over glass substrate to make white light, followed by red, green and blue filters to make three colour lights.'

Tick... tock...

You might think that with the widespread use of quartz crystals and atomic clocks that most of our timekeeping problems have been solved. However, when it comes to precise time measurements it seems you can never be too accurate, and research continues to push the boundaries of what is possible.

Writing in the journal *Optica*, researchers have designed a new kind of atomic clock using strontium atoms. 'We want to improve the timekeeping infrastructure all over the world by building better and better clocks and integrating them into the time-keeping infrastructure,' said Christian Grebing, a researcher at the Physikalisch-Technische Bundesanstalt in Germany.

The traditional element for atomic clocks is caesium. Atoms are subject to microwaves and their resulting precise and repeatable oscillations between energy states is the 'pendulum' used to measure time. In general, the faster the oscillation the more precise the measurement, which is where strontium comes into the picture because it oscillates 47 times faster than Caesium, leading to a near-fourfold increase in potential accuracy.

The new design is so accurate that theoretically it would have an error of just 100 seconds since the Big Bang that started the universe.

Why would you need such accuracy in everyday life? Well, there are applications that many of us use that need extremely good time measurement. For example, the satellites at the heart of GPS systems need to know the time to with in a few nanoseconds, an accuracy so demanding that the relativistic effects of the satellites' motion have to be taken into account.

IoT hearing aid

Oticon has launched an Internet of Things (IoT) hearing aid, the 'Opn'. It's the first dual communication system that combines binaural processing with streamer-free, Internet connectivity, without compromising battery life or physical size.

The Opn is compatible with the web-based service IFTTT (If This Then That), unlocking potential for connected device communication. The Opn, can be programmed to talk directly with door bells, smoke detectors and baby alarms – connecting to and interacting with the Internet and other IoT-enabled devices.

Next-generation Bluetooth from Microchip

Microchip has announced two next-generation Bluetooth Low Energy (BLE) product solutions with an easy-to-use ASCII-style command interface that makes the devices easy to configure and eliminates any complicated code compiling. The RN4870 and RN4871 support the latest Bluetooth 4.2 specification and have a Bluetooth stack on board with a scripting engine to enable standalone operation and eliminate microcontroller (MCU) use for simple applications. These next-generation Bluetooth devices enable fast time to market and improve the total manufacturing cost.

The new devices deliver up to 2.5-times data throughput improvement over previous generation products based on the Bluetooth 4.0 standard. In addition, the new Bluetooth solutions offer connection security based on Federal Information Processing Standards (FIPS) coupled with advanced features. The devices can seamlessly transfer serial data over BLE devices and can support different beacon formats such as iBeacon or Eddystone via a single command. Both devices with a shield option are fully certified to meet worldwide regulatory standards and are available with compact package options as small as 6 × 8mm. This, combined with Microchip's user-friendly interface, helps speed customers' time to market.

Also available from Microchip is the RN4870 Bluetooth 4.2 Low-Energy PICtail/PICtail Plus Daughterboard with a sensor board (RN-4870-SNSR).

For more information, visit Microchip's website at: **www.microchip.com/RN4870_Wireless6321**

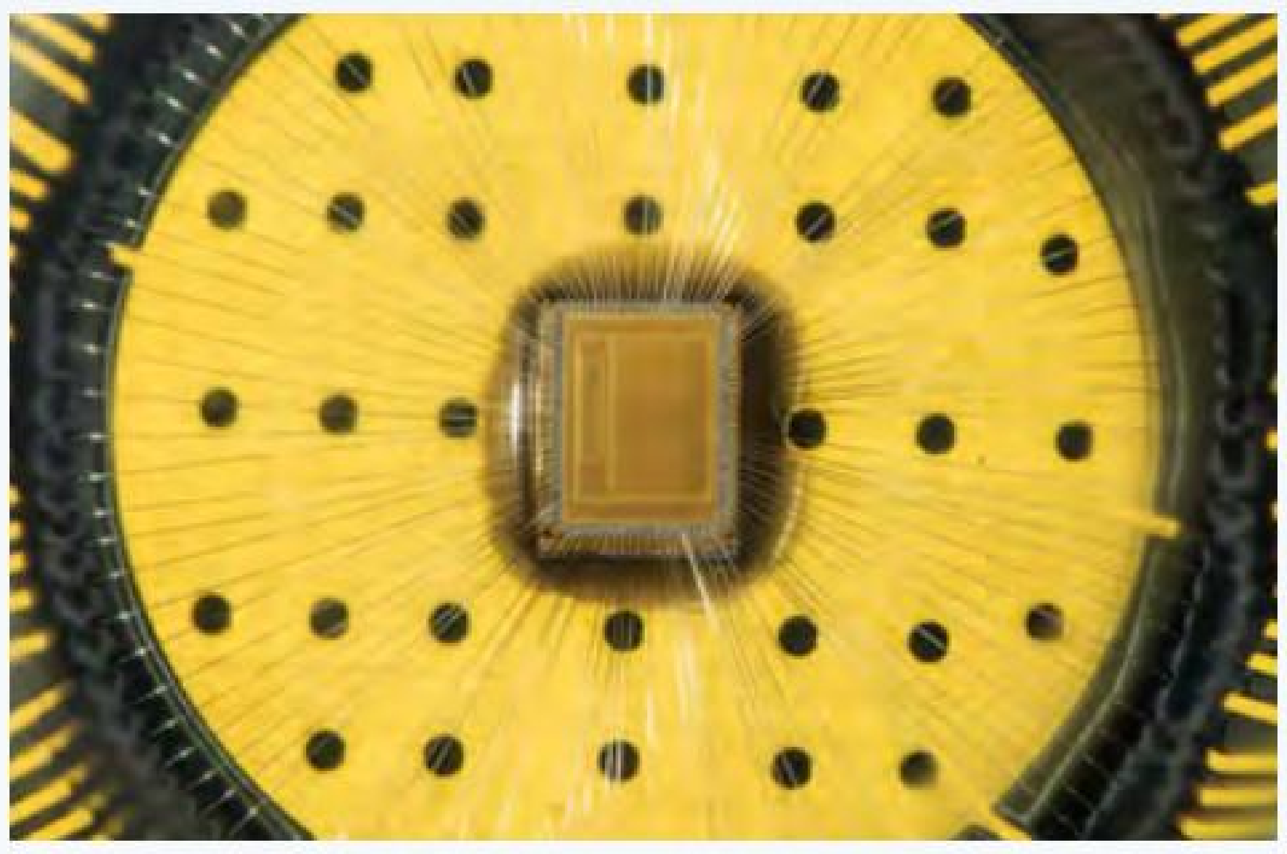
Bluetooth Low Energy Applications
Connected
Home Medical Monitor
Medical Device
Wearable
Lights
House Key
Wireless Sensor
Remote Control
MICROCHIP
RN4871

Tetris Megaprocessor

In last month's *Techno Talk* column Mark Nelson described the MOnSter 6502, a fully working discrete component reproduction of the famous 6502 microprocessor. James Newman in Cambridge has gone several steps further and built a 'Megaprocessor' from individual transistors, diodes and other discrete parts. This 42,400-transistor, half-ton, 500W, 8/16-bit machine can be used to play the famous computer game *Tetris*, and James has written an amusing and informative account of his impressive project at: **www.megaprocessor.com**

In answer to the obvious question as to why he did it, James has provided two answers: the long version states – 'Computers are quite opaque, looking at them it's impossible to see how they work. What I would like to do is get inside and see what's going on. Trouble is we can't shrink down small enough to walk inside a silicon chip. But we can go the other way; we can build the thing big enough that we can walk inside it. Not only that, we can also put LEDs on everything so we can actually see the data moving and the logic happening. It's going to be great.' Plus a short answer that all *EPE* readers can relate to – 'Because I want to'!

Phase Change Memory cell

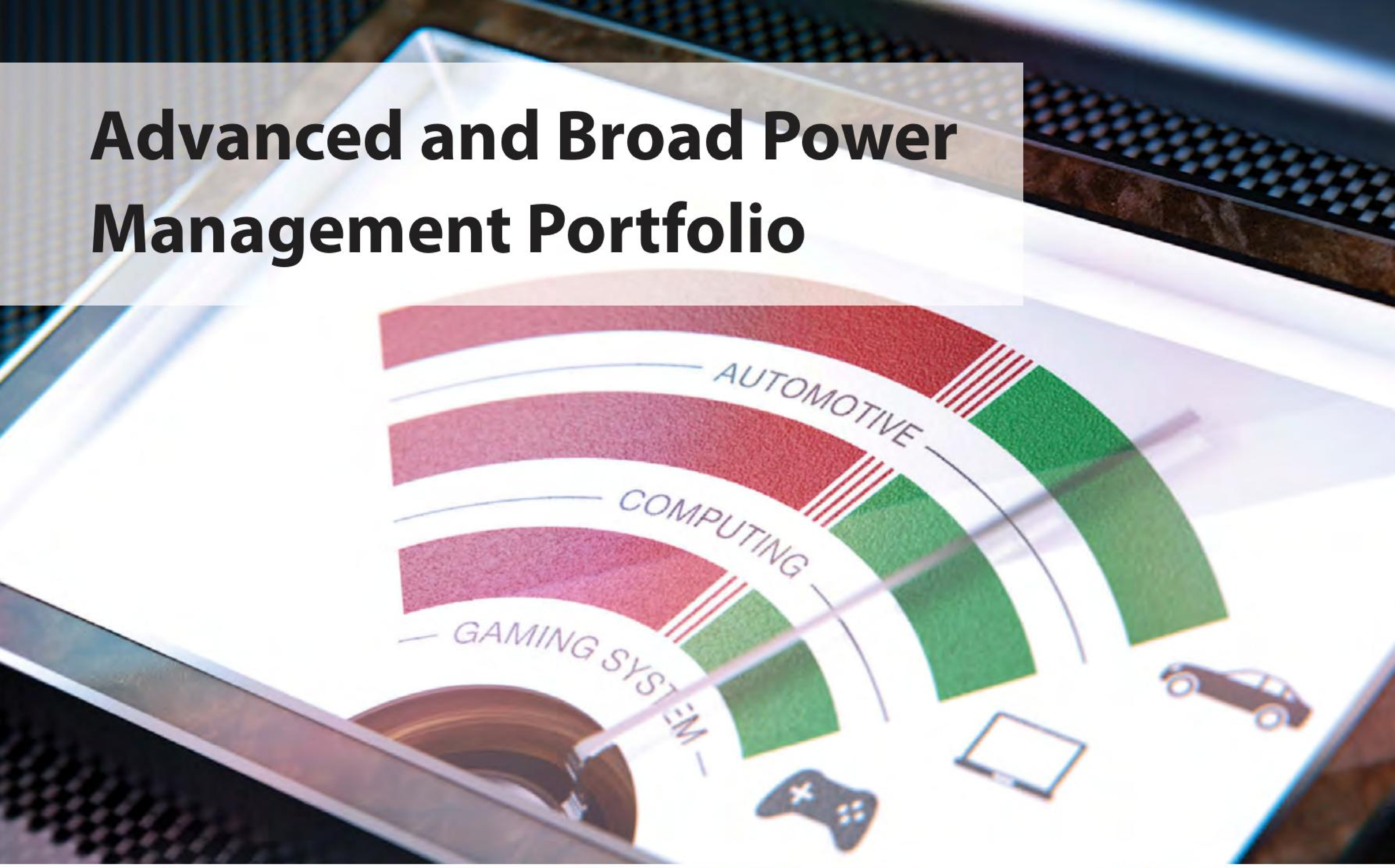


IBM's PCM chip

For the first time, scientists at IBM Research have demonstrated reliably storing three bits of data per cell using a relatively new memory technology known as phase-change memory (PCM).

The current memory landscape spans from venerable DRAM to hard disk drives to ubiquitous flash. But in the last few years PCM has attracted the industry's attention as a potential universal memory technology based on its combination of read/write speed, endurance, non-volatility and density. For example, PCM doesn't lose data when powered off, unlike DRAM, and the technology can endure at least 10 million write cycles, compared to an average flash USB stick, which tops out at 3,000 write cycles.

Advanced and Broad Power Management Portfolio



Microchip Technology has an expansive offering of power management solutions to fit virtually every type of design criteria. From the smallest form factor needed for mobile devices to complex industrial power management designs to automotive standards, you are sure to find a highly integrated solution to meet your needs. If you are looking for greater flexibility in your design, Microchip's digitally enhanced power analog devices integrate a microcontroller (MCU) or digital signal controller (DSC) for a fully programmable and flexible solution.

Applications:

- LDO and switching regulators
- Charge pump DC/DC converters
- Power MOSFET drivers
- Digitally enhanced and PWM controllers
- System supervisors
- Voltage detectors
- Voltage references
- Li-Ion/Li-Polymer battery chargers
- Power MOSFETs

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TechnoTalk

Bigger than mobile

Mark Nelson

That's the forecast pundits are making for the Internet of Things. They speak of 'a game-changer for the mobile radio industry' – a market worth $3 trillion using 28 billion devices within five years. Making it work involves all manner of new technologies, some of which we might adopt for *EPE* projects. So what's not to like?

NEW TECHNOLOGIES NEARLY always offer unforeseen opportunities for technology transfer, enabling clever applications that the original protagonists never foresaw. I have a great admiration for imaginative electronicists who subvert new techniques and use them imaginatively in new ways for hobby projects. And that surely is one of the reasons why you are reading this magazine and article too. So let's crack on...

Disruptive technology

The public Internet and its close cousins the commercial and military intranets were intended and designed for use by human beings. But now we have the Internet of Things (IoT) coming along, focussed specifically on machine-to-machine (M2M) communication. The IoT enables physical devices, vehicles, buildings and other items – embedded with electronics, software, sensors and other gizmos and enabled with networking capability – to collect and exchange data and unburden life in general. After all, who wants to go outdoors to note down their gas and electricity meter readings and type them into the supplier's website? Yet, that's what others and I have to do every month to get rock-bottom-priced energy.

According to a recent report by Swedish company Ericsson, there will be around 28 billion connected devices on Planet Earth by 2021, of which 12 billion are connected using cellular radio or mobile broadband. In fact, by 2018 the IoT messages sent over mobile will outnumber voice calls (which explains the title of this article). That's one classic example of disruptive technology! Incidentally, if all this sounds like gobbledy-geek to you I suggest taking a look at the excellent Wikipedia article on the IoT at: **https://en.wikipedia.org/wiki/Internet_of_things**

Ericsson's Chief Strategy Officer Rima Qureshi asserts: 'IoT is now accelerating as device costs fall and innovative applications emerge. From 2020, commercial deployment of 5G mobile networks will provide additional capabilities that are critical for IoT, such as network slicing and the capacity to connect exponentially more devices than is possible today.' Fighting talk and welcome news for mobile operators and equipment manufacturers. But is she correct?

LoRa says no

The adoption of the IoT will be driven by connected cars and smart metering (intelligent utility meters), a prediction with which few will disagree. But while constant communication by garrulous gas meters will do wonders for the profits of Vodafone, O2, Three and the other mobile operators, it could also load heavy costs onto consumers of gas, water and electricity. Utility providers would much prefer to use a less expensive datacomms technology and now their prayers have been answered. An imaginative industry consortium by the name of LoRa offers an ingenious comms technique that promises to snatch business away from the mobile operators and is every bit as disruptive as IoT itself. What's more it has potential prospects for hijacking by enterprising hobbyists who require cheap datacomms – read on!

An 'obvious' alternatives to using mobile networks for IoT purposes might be wireless systems such as Wi-Fi or Bluetooth, but their range is restricted and not every household has a broadband connection. That's where LoRa (an abbreviation for 'long-range radio') comes in. Developed and patented by the Semtech company, LoRa offers a solution that is both economically viable and offers greater range. This two-way wireless solution complements M2M cellular or Wi-Fi infrastructure, providing a low-cost way to connect battery-operated and mobile devices to either the network infrastructure or an end point. LoRa claims to deliver ranges of up to 15km (10 miles) under line-of-sight conditions, employing just flea power (100mW into the antenna). This enables users to slam the door on expensive mobile communications and significantly extends the scope of wireless for M2M applications.

Working wonders

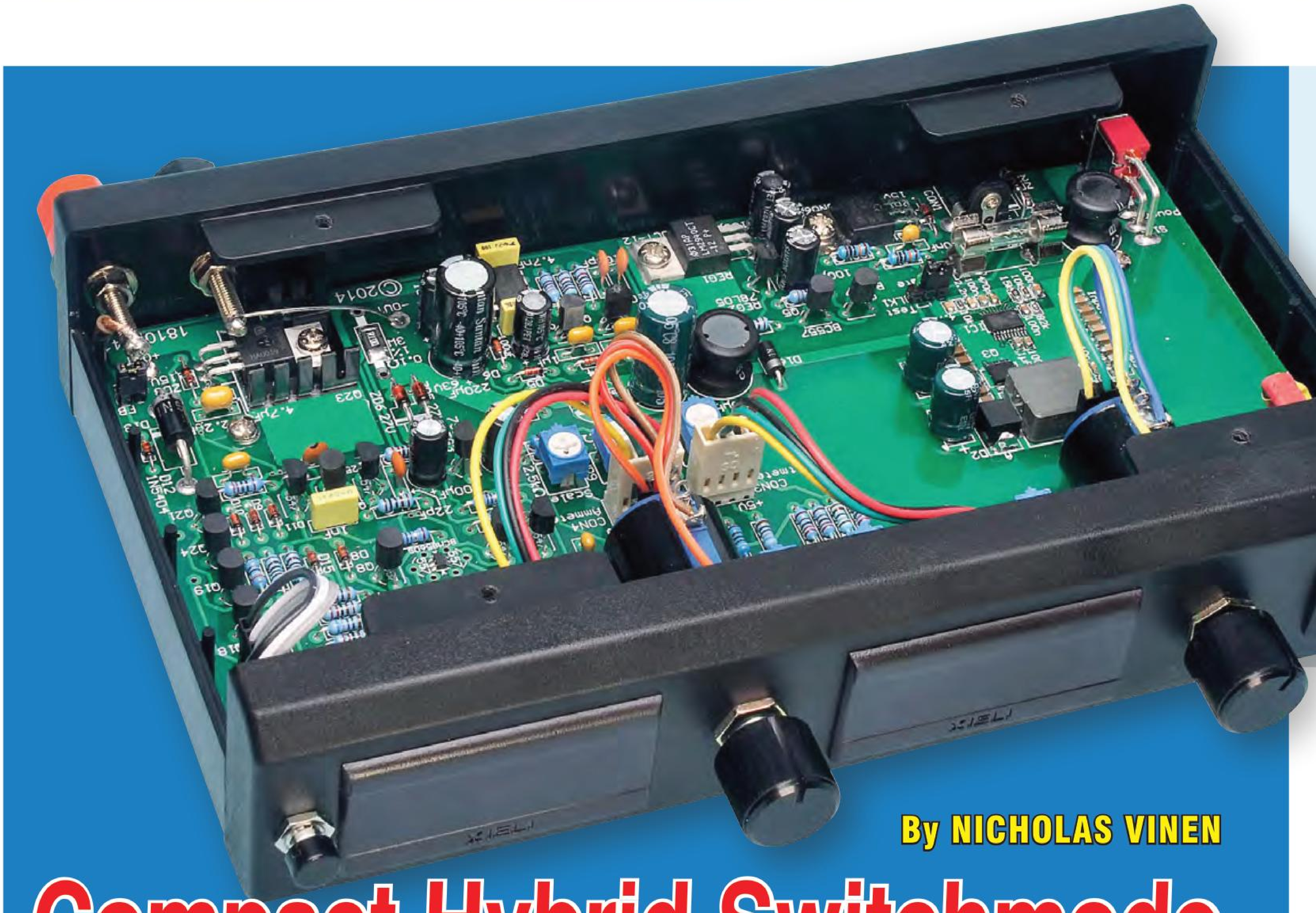
How on earth can this be achieved? Quite easily in fact, using (i) extremely sensitive receivers, (ii) band-spreading (transmitting over a greater bandwidth than normal – up to 500kHz – which elevates the received power per data-bit by quite a few dB) and (iii) a fairly slow data rate (37.5kbit/s maximum, which is not a problem with data that is not blindingly urgent). This combination of factors makes it possible to span distances of more than 15km at low bit-rates. Economy is achieved by designing wireless networks covering many square kilometres with hundreds of end-nodes and a 'gateway' comms node located at the physical middle point of the cell. The 868MHz band is being used for LoRa, although other countries have frequency ranges available around 915MHz, as well as at 433MHz and 477MHz. LoRa is less than two years old, but this alliance already has more than 300 members world-wide and some of this technology may trickle down to our kind of applications. For more information, check out **www.semtech.com/wireless-rf/iot.html** and **www.lora-alliance.org**

Even more disruption

Many utility meters and other IoT devices do not have mains power close by, so is this a problem? Actually no, thanks to a third example of disruptive technology, making chips with ultra-low power needs. These can harvest energy from the environment and store it in super-capacitors.

In Finland, the VTT Technical Research Centre of Finland has just demonstrated a micro-super-capacitor that can be integrated directly inside a silicon microcircuit chip. This tiny energy supply can store electrical energy generated by thermal, optical and vibration energy harvesters, and supply the electrical energy when needed. This is vitally important for autonomous sensor networks, wearable electronics and mobile IoT electronics. An impressive power capacity of two watts can be stored on one square centimetre of silicon substrate, leaving the surface of the chip available for active integrated microcircuits and sensors – see: **www.vttresearch.com/media/news/novel-energy-inside-a-microcircuit-chip**

The future is zero-power, so how long will it be before we see the first *EPE* IoT project that is totally eco-powered?



By NICHOLAS VINEN

Compact Hybrid Switchmode 100W Bench Supply – Part 1

Includes dual voltage and current metering

This very compact bench supply can deliver 0-40V at up to 5A with accurate and fast current limiting and has 3.5-digit 7-segment LED readouts for simultaneous voltage and current display. You can power it from any 12-24V DC supply such as a PC or laptop power supply or lead-acid/lithium battery. It uses a combination of switchmode and linear circuitry to obtain good regulation and low residual noise.

NORMALLY, YOU would expect any adjustable power supply capable of producing up to 40V and 5A to be a great deal larger than this little unit. In fact, it fits into a tiny half 1U rack plastic case. It measures just 209 × 43 × 122mm (W × H × D), not including the knobs and rear terminals. So how have we managed this feat of miniaturisation?

The first point is that it is really just an elaborate regulator and is meant to be powered by a laptop supply or similar. Second, the circuitry is housed on one double-sided plated-through PCB which employs some surface mount devices and MOSFETs selected for low-on resistance to produce very little heat dissipation inside the case.

We have combined the benefits of switchmode and linear regulator

Left: the unit is built into a compact half 1U rack plastic case measuring just 209 × 43 × 122mm (W × H × D), not including the knobs and rear terminals. It comes with the panel meters and load switch already fitted.

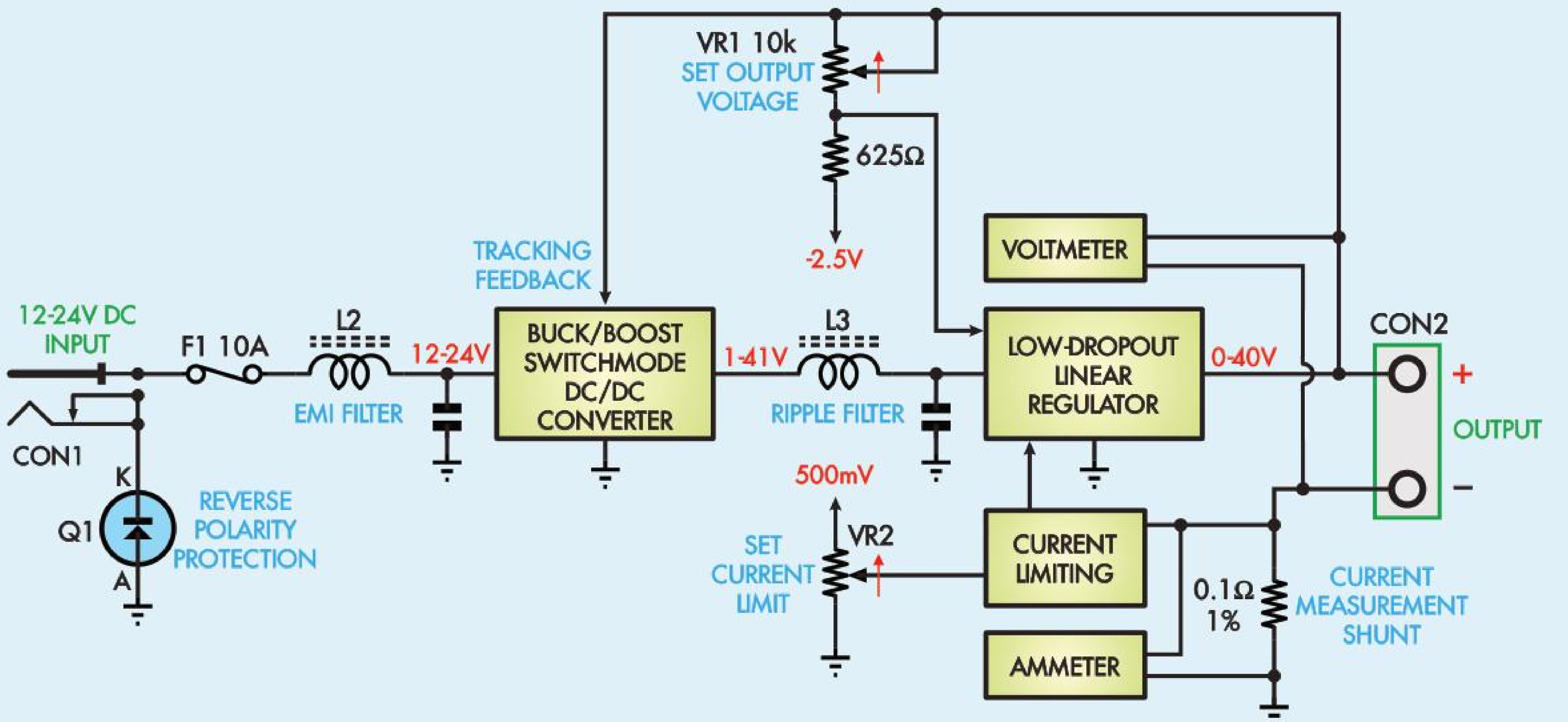


Fig.1: block diagram of the switchmode/linear bench supply. The output voltage is adjusted using VR1 which provides feedback to the low drop-out linear regulator section, which acts to maintain the feedback potential at 0V. VR2 sets the current limit to 0-5A, while the buck/boost switchmode section monitors the output voltage of the linear regulator and adjusts its output to provide about 0.7V 'headroom' at the regulator's input.

circuitry. Its output is adjustable over the range of 0-40V and unlike some designs, goes all the way down to 0V. Its current limit is adjustable from 0-5A and has fine resolution so that low currents can be accurately set. The dual LED panel meters constantly display the output voltage and current and the current limit can be displayed and set without having to short the outputs. It also has a front-panel load switch; this lets you set up the required voltage before switching on power to the load.

Being a hybrid design (switchmode *and* linear), it has much lower output noise (hash) than a pure switchmode bench supply and also doesn't need a large output capacitor bank that would then be dumped into the load in case of a short circuit. In fact, when the current limit kicks in, the output voltage drops very rapidly and the unit goes into current regulation mode. In other words, it can also be used as a near-ideal current source.

Since it runs off a low-voltage DC input, it can even be used away from 230VAC mains and powered from a car/truck/caravan battery or even a portable battery pack.

The dual voltage/current displays are really handy for a bench supply if you need to check that you have set the right output voltage and monitor the current draw while you are performing your tests. It's also quite handy to be able to see what the output voltage has dropped to, should current limiting be activated.

One feature missing from some cheap current-limited bench supplies is the ability to view the current limit setting without shorting the output leads. This is especially useful if you want to adjust the current limit while the load is powered since otherwise you really have no way to know what you've set it to while the load is drawing less current than the limit.

Buck/boost converter

The switchmode-based bench supplies we have published in the past have typically used a relatively large mains transformer to charge a capacitor bank to around 50V. They then used a step-down ('buck') switchmode converter to produce the required output voltage efficiently. This means the supply produces much less heat than a linear design of an equivalent power level.

In this case though, we wanted to fit the supply into this neat case from Altronics which comes with the panel meters and load switch already fitted. That ruled out using a large internal transformer. So we had the idea of powering it from a high-current DC supply which constructors may already possess, such as an old PC power supply or laptop charger. If you're like us, you have a few of these lying around, just waiting to be used for something grand.

PC supplies usually deliver the most current from their 12V output while laptop supplies normally give 15-24V with the most common being 17V. This means that our bench supply needs to be able to step the incoming supply voltage either up or down, depending on the required output voltage. And to be truly useful, it needs to do this efficiently at a reasonably high power level, matching that available from a typical laptop supply (60-100W).

To achieve this, we are using a 'buck/boost' switchmode converter. This is similar to the more common 'buck' type, but it can produce an output voltage that's higher, lower or the same as the input voltage. The particular chip we are using (the LM5118 from National Semiconductor, now Texas Instruments) operates in buck mode, boost mode or an intermediate buck/boost mode, depending on the ratio of the output to input voltages. We'll explain how this works in more detail below.

As a result, this supply can deliver plenty of current at lower voltages, up to about 15V, and then a lesser but still significant current up to the maximum 40V output (2.5A+, depending on the input DC supply voltage and power). Most bench supplies only go up to 30V and while this is sufficient for many tasks, we sometimes find it a bit limiting, hence the decision to go to 40V, even with a reduced current capability.

Performance

As mentioned briefly above, switchmode-based bench supplies always have some of the high-frequency

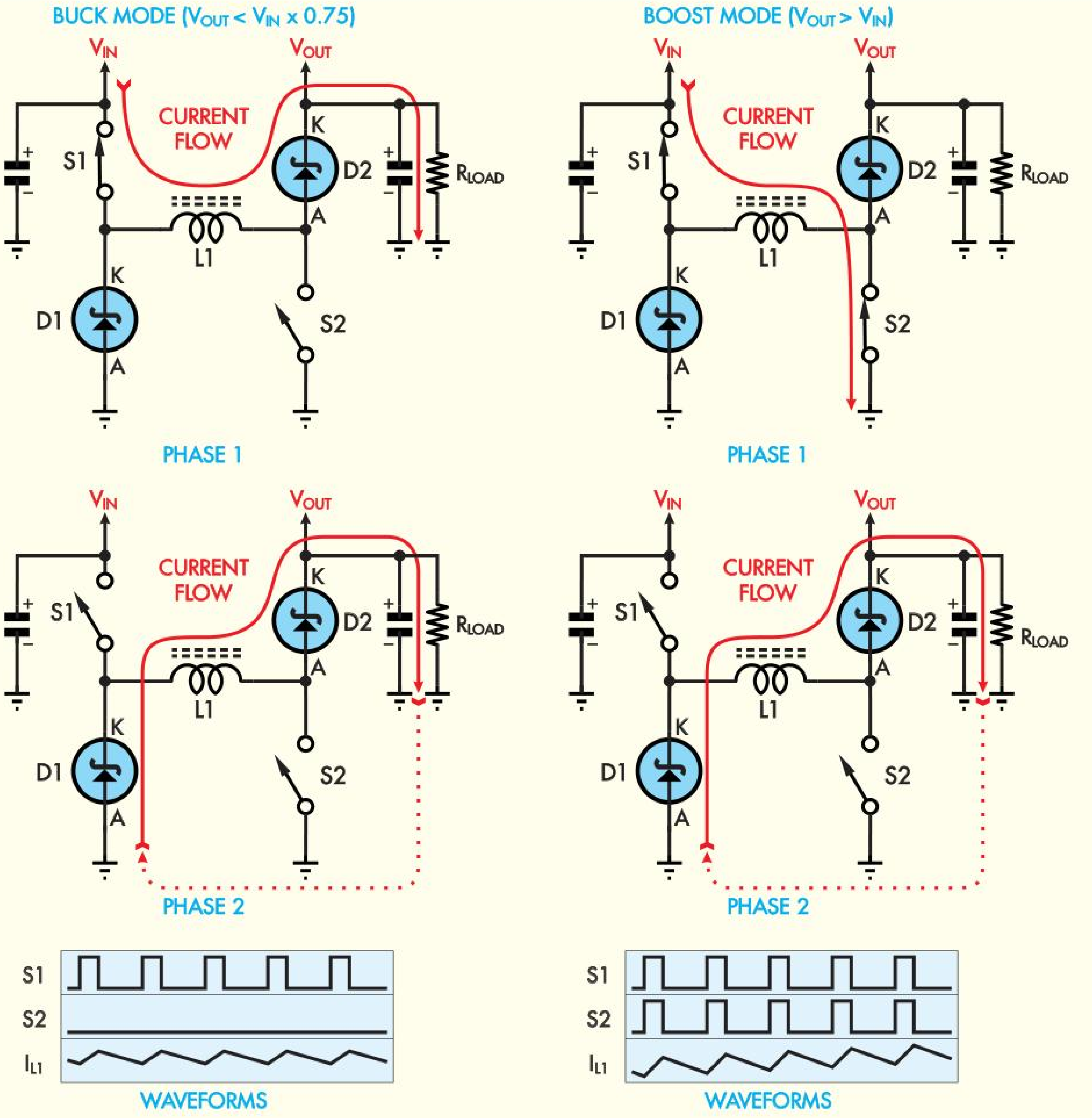


Fig.2: an illustration of how the switchmode converter works, in buck mode (diagrams at left) and boost mode (diagrams at right). The mode of operation is determined by whether S2 (actually a MOSFET) is switched with S1 or just left open (ie, off). In buck mode, as the duty cycle approaches 100%, the output voltage approaches the input voltage. In buck/boost mode, a 50% duty cycle gives an output voltage that's equal to the input, with higher duty cycles boosting the output voltage above the input, approximately doubling it at 75% duty cycle, quadrupling it at 87.5% and so on.

switching components present as 'hash' in the output, while an ideal bench supply should have pure DC with no noise or hash. In many cases, a switchmode-based bench supply will have an LC filter (or possibly a more complex filter involving a differential-mode choke) at the output to attenuate the noise, but this is only partially effective and also adversely affects output regulation.

Adding a linear regulator stage after the switchmode stage is a better proposition. This can offer greater noise and ripple rejection and depending on the dropout voltage it operates with, can also result in much better transient load response. In other words, it can cope better with sudden changes in load impedance/current draw, resulting in smaller variations in output voltage under these conditions.

Without getting into a lot of detail, the reason for this is that switchmode regulators tend to be quite heavily 'compensated', ie, their 'closed loop' bandwidth is purposefully reduced to a few kilohertz. This is necessary because the inductor and capacitors which are used to convert the switching output to a smooth voltage form a low-pass filter which leads to a delay between changes in the switching waveform and changes in the output voltage.

This delay is a form of phase shift; quite a large one in fact. And feedback systems with large phase shifts are unstable unless the gain is limited at higher frequencies. Linear regulators (depending on design) can have much smaller phase shifts, allowing more feedback bandwidth and thus much more rapid response to any changes in the output voltage due to the behaviour of the load.

Having a linear regulator at the output also means that we can implement the current limiting feature there. With the linear regulator's high bandwidth, that means it can provide a smooth current flow even in the face of rapidly varying load impedance and it also means there can be a very small output capacitance, so that there isn't much stored energy that will flow through the load before the current limit is effective. In this case, a 2.2µF output capacitor delivers a maximum of 1.75mJ of energy (with the output set to 40V) into a dead short.

So you can see that combining a switchmode and linear regulator gives us the best of both worlds. Well, it isn't quite perfect – some switching noise will still make it through the linear regulator, for example. However, it's a highly effective combination and a better compromise than either type of regulator by itself. Implementing it effectively is a bit tricky though, as we shall see.

Design concept

Fig.1 is the block diagram, which shows the overall design of the supply. The output voltage and current are controlled by the low-dropout linear regulator section, with VR1 adjusting the voltage and VR2 the current.

VR1 forms part of a voltage divider between the output and a –2.5V reference voltage. If the feedback voltage is above 0V, the regulator reduces its output, while if the feedback is below 0V, the output voltage is increased. The values selected give the unit a range of 0-40V.

The LDO regulator needs an input voltage that's slightly higher than its output voltage for proper regulation (at least 0.1V but ideally a bit more). As a result, the switchmode converter monitors this output voltage and attempts to maintain its own output at a slightly higher voltage. The 'headroom' is set at around 0.7V, so the output of the switchmode regulator will go slightly above 40V and normally never drops to zero.

An LC filter between the two regulators reduces high-frequency ripple fed to the linear regulator, as its input supply/ripple rejection is best at lower frequencies. There is a similar filter at the input of the switchmode regulator to stop too much noise coupling back to the input and possibly radiating EMI from the input wiring.

A 10A fuse protects the circuit against serious faults, however if the switchmode section is working normally, its cycle-by-cycle current limiting will mean that the fuse should never blow. Q1 provides input reverse polarity protection; although it operates as a diode, it is actually a MOSFET to avoid reducing the supply voltage too much and wasting a lot of power, as a standard diode would.

The voltmeter is wired across the output terminals while the ammeter displays the voltage across the shunt. Note that the voltage across the shunt is effectively subtracted from the output voltage, but the way the feedback network is connected automatically compensates for this (as explained later).

We have used 10-turn potentiometers for voltage and current adjustment as this makes it easier to set these values accurately; we recommend constructors do the same – however, there is nothing stopping you from using the cheaper 270° rotation pots should you wish.

Buck/boost operation

Most of the switchmode regulators we have published in the past have been one of three types, either ‘buck’, ‘boost’ or based around a transformer. The buck and boost types are the simplest; however, the former can only reduce the input voltage while the latter can only produce an output greater than the input. Hence the use of buck/boost, which gives a much wider range of output voltages.

The LM5118 IC operates in buck mode when the output voltage is less than three quaters the input voltage, and boost mode when the output voltage exceeds the input voltage. Between these, it operates in an intermediate mode which is partly buck and partly boost, ie, buck/boost.

Fig.2 shows the difference between the two main modes. At left are the two states used for buck mode. When S1 is on, current can flow from the input straight to the output, via inductor L1 and Schottky diode D2. During this time, L1’s magnetic field charges up and the current flow smoothly ramps upwards, at a rate determined by the voltage across L1 and its inductance.

When S1 is switched off (below), L1’s magnetic field continues to drive current through the load via D2, but this current can no longer come from V_{IN}, so it must flow through Schottky diode D1 from ground. The dotted line shows how current recirculates – the only source of energy during S1’s off time is L1’s magnetic field. As such, the current flow smoothly drops, again at a rate limited by the voltage across L1 (now roughly equal to the output voltage) and its inductance.

This cycle repeats and the ratio of S1’s on-time to off-time, in combination with the load impedance, determines the ratio of the output voltage to the input voltage, but this is always less than one. Some example waveforms are shown below these diagrams, for a steady state (ie, constant load and output voltage).

Compare these diagrams to those at right, which show operation in boost mode. The difference is that now S2 switches on simultaneously with S1. This increases the voltage across L1 to be the full input supply voltage and this does not drop over time, so L1’s magnetic field charges up much faster. Thus, more current is delivered during the off-time (below) and hence the output voltage is higher for the same duty cycle as buck mode.

It stands to reason then that the ratio of the output voltage to the input voltage can be greater than one and in fact, it is inversely proportional to the duty cycle. Thus, the maximum output voltage is limited mainly by the maximum duty cycle, which for the LM5118 is related to the operation frequency (as there is a fixed minimum off-time). In our circuit, maximum duty cycle is about 85%, giving a maximum boost ratio of about 4:1, certainly sufficient to get an output of over 40V from an input of 12V.

When in the intermediate mode mentioned above, the only difference is that S2 switches off before S1, thus giving three phases for each cycle, equivalent to phase 1 for boost, followed by phase 1 for buck and then phase 2 (same in either mode). Thus, the boost ratio is not as high as in pure boost mode. This intermediate mode means there is no discontinuity in the converter’s operation or output voltage.

Circuit description

Now let’s turn to the full circuit. Fig.3 shows the main section. At its heart is the buck/boost switchmode converter, controlled by IC1 (LM5118). First, let’s look at the ‘output’ side of IC1, ie, pins 12-20. These drive the MOSFETs which do the actual switching.

Pin 19 is the high-side driver output which connects to the gate of Q2 (S1 in Fig.2). Pin 20 is connected to the source of this MOSFET, which is the ‘floating’ node that switches between ground and the incoming supply rail. This pin is used as the ground return for the discharge current from the MOSFET gate and as a negative reference when driving it high, charging the gate to this voltage plus about 7V.

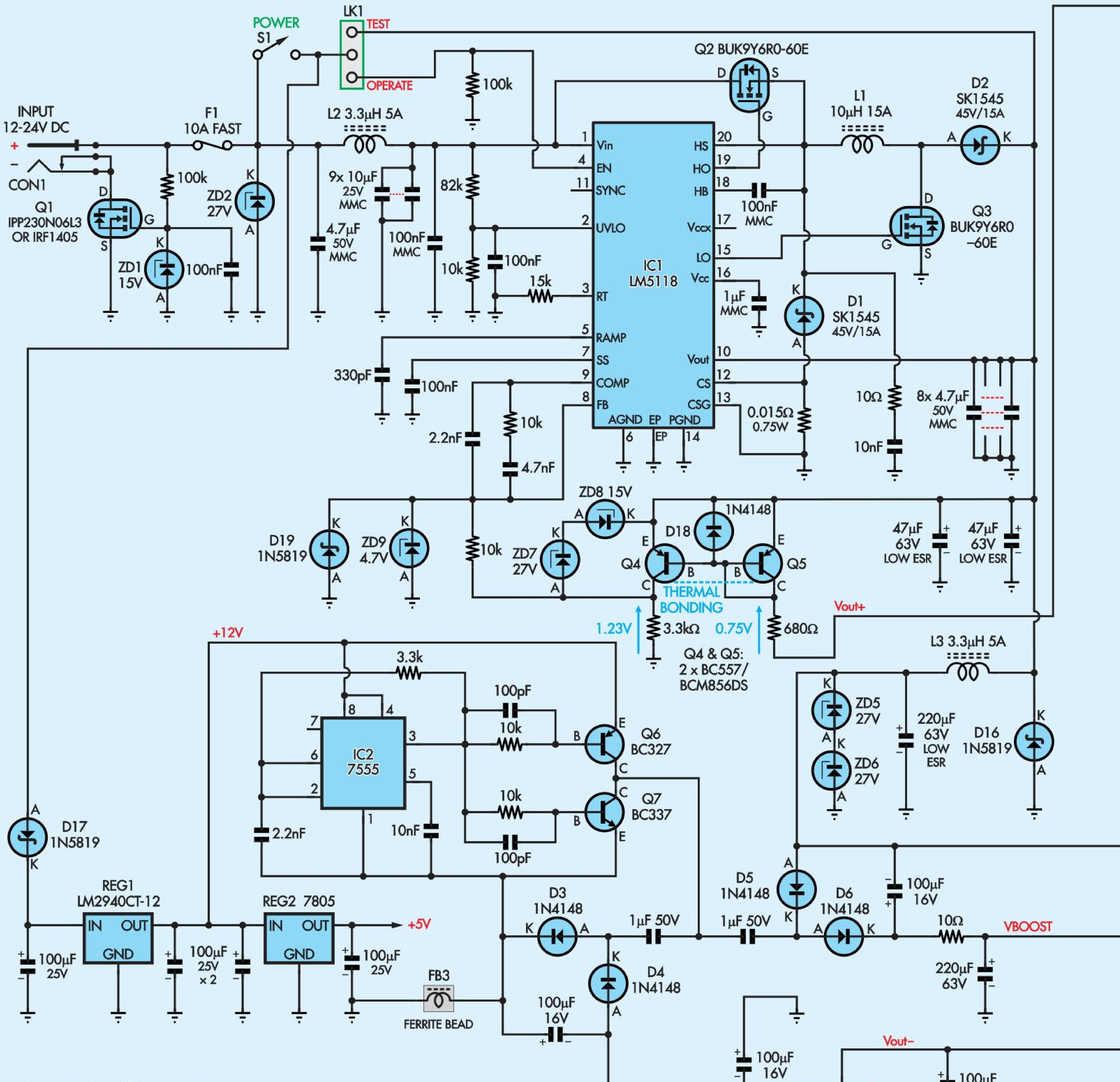
Thus if the input voltage is say 14V, the gate of Q2 must be driven to 21V. To generate this higher voltage, IC1 has an internal charge pump and it uses the 100nF capacitor between pins 18 and 20 to accomplish this. This capacitor is charged to 7V from the input supply when pin 20 is low and current then flows back from it into the MOSFET gate when pin 20 goes high, boosting the pin 18 voltage to the required level. This arrangement is known as a ‘floating high-side driver’.

The low-side (boost) MOSFET, Q3, is driven from pin 15. This does not require a charge pump as its source terminal is connected directly to ground and thus the gate only needs to reach about 5V for full conduction.

Q2 and Q3 are logic-level MOSFETs which are switched fully on with a gate-source voltage of 5V. IC1 has an internal 7V regulator with a 1µF output filter capacitor connected from pin 16 to ground and this determines the maximum gate-source voltage fed to the two MOSFET gates. An external supply can be connected to pin 17 (V_{CCX}) but the internal regulator can supply enough current to operate the MOSFETs at 350kHz without excessive dissipation (a maximum of about 650mW).

Ground return for the low-side MOSFET driver is pin 14 (PGND) while pins 12 and 13 are used to sense the voltage across a 15mΩ shunt connected in series with the buck recirculating diode, D1. This sets the peak current limit to 125mV / 15mΩ = 8.3A in buck mode and 250mV / 15mΩ = 16.6A in boost mode (close to the inductor’s saturation current). The inductor current is sampled just after the MOSFET(s) switch off, when it is at its peak, just after D1 becomes forward biased.

Note that the switchmode arrangement is based largely on the sample circuit in the LM5118’s data sheet, which provides a design with similar requirements to ours. We require a maximum boost of 40V / 12V = 3.3


POWER
S1
LK1
TEST
OPERATE
100k
Q2 BUK9Y6R0-60E
D
S
G
INPUT
12-24V DC
+
–
CON1
F1
10A FAST
L2 3.3μH 5A
L1
10μH 15A
D2
SK1545
45V/15A
A
K
100k
Q1
IPP230N06L3
OR IRF1405
D
G
S
ZD2
27V
ZD1
15V
100nF
9x 10μF
25V
MMC
4.7μF
50V
MMC
100nF
MMC
82k
10k
100nF
15k
1 Vin
4 EN
11 SYNC
2 UVLO
3 RT
5 RAMP
7 SS
9 COMP
8 FB
AGND EP PGND
6 EP 14
IC1
LM5118
20 HS
19 HO
18 HB
17 Vccx
15 LO
16 Vcc
10 Vout
12 CS
13 CSG
100nF
MMC
1μF
MMC
Q3
BUK9Y6R0
–60E
D1
SK1545
45V/15A
330pF
100nF
2.2nF
10k
4.7nF
0.015Ω
0.75W
10Ω
10nF
8x 4.7μF
50V
MMC
ZD8 15V
1N4148
D18
D19
1N5819
ZD9
4.7V
10k
ZD7
27V
Q4
Q5
E
B
C
THERMAL
BONDING
47μF
63V
LOW ESR
47μF
63V
LOW ESR
Vout+
1.23V
3.3kΩ
0.75V
680Ω
Q4 & Q5:
2 x BC557/
BCM856DS
L3 3.3μH 5A
+12V
3.3k
100pF
10k
IC2
7555
8 4 7 6 2 3 5 1
Q6
BC327
Q7
BC337
10k
100pF
2.2nF
10nF
ZD5
27V
ZD6
27V
220μF
63V
LOW
ESR
D16
1N5819
D17
1N5819
REG1
LM2940CT-12
IN OUT
GND
100μF
25V
100μF
25V
× 2
REG2 7805
+5V
100μF
25V
FB3
FERRITE BEAD
D3
1N4148
1μF 50V
D4
1N4148
100μF
16V
D5
1N4148
1μF 50V
D6
1N4148
100μF
16V
10Ω
VBOOST
220μF
63V
100μF
16V
Vout–
GND
IN OUT
REG3 79L05
100μF
16V
10Ω

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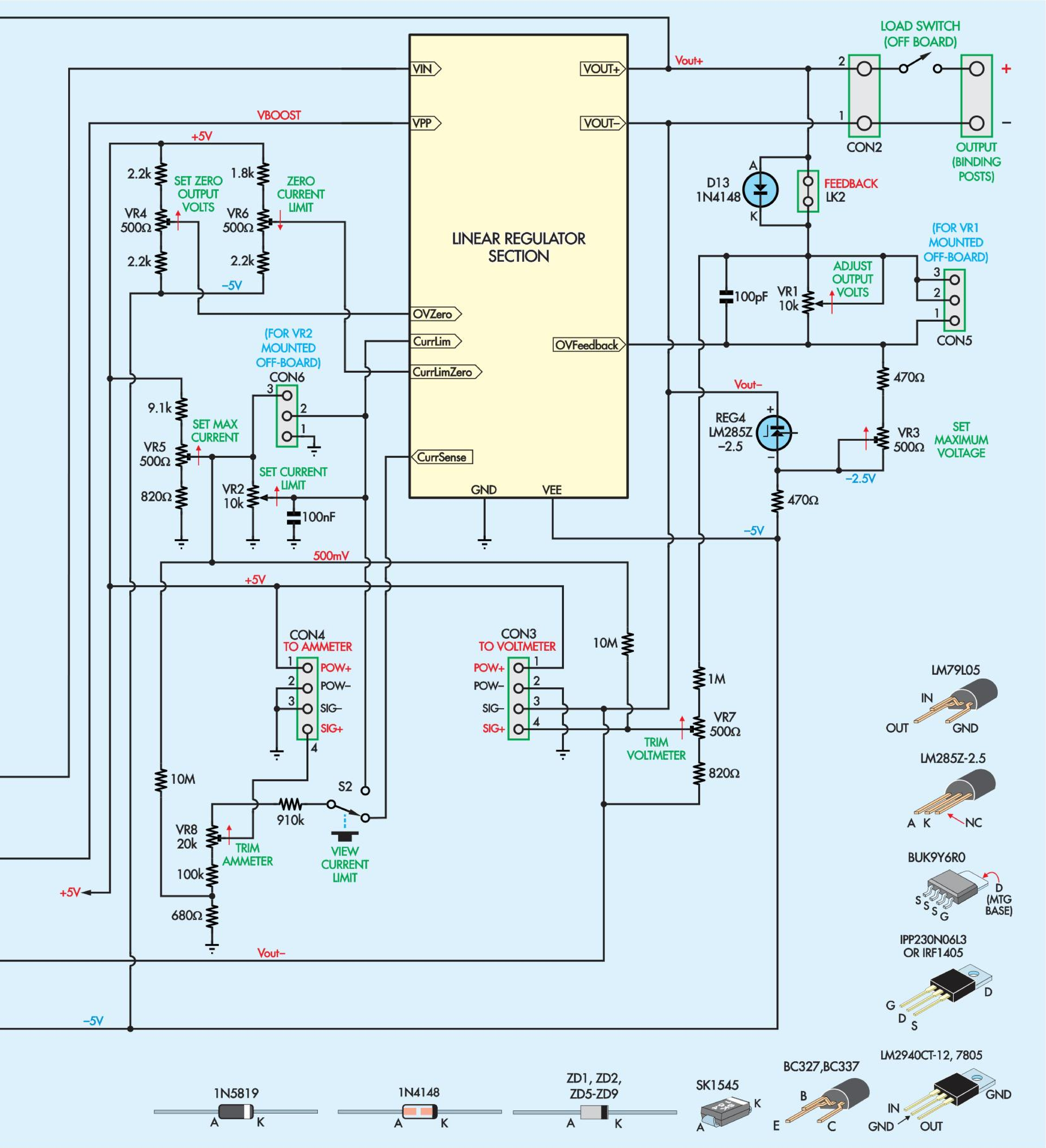
SWITCHMODE-LINEAR HYBRID BENCH POWER SUPPLY MAIN CIRCUIT DIAGRAM

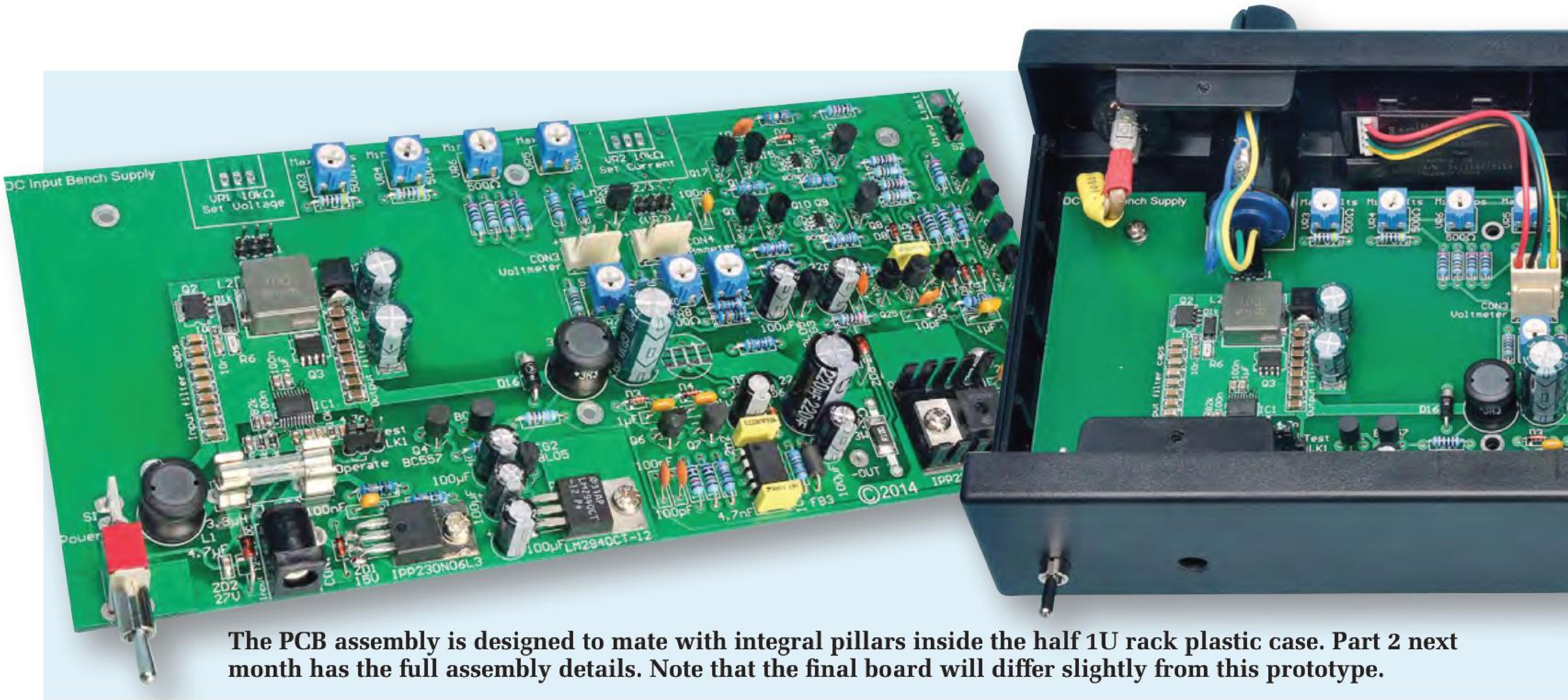
Fig.3: the main section of the bench supply circuit. IC1 is the buck/boost controller and this drives MOSFETs Q2 and Q3, which form the switchmode converter in conjunction with inductor L1 and Schottky diodes D1 and D2. The output then goes to the linear regulator (shown in detail next month) and then to the output terrminals. The output current is checked using a 0.1Ω shunt resistor which is monitored both by the ammeter panel and the current limit circuitry. REG1-REG3 and IC2 generate two extra supply rails for the linear regulator circuitry, one about 10V above the main supply rail (V_{BOOST}) and a –5V rail, using a charge pump driven by Q6 and Q7. VR1 and VR2 set the output voltage and current limit while VR3-VR8 zero and adjust the meter displays, output voltage range and current limit range.


LINEAR REGULATOR SECTION
VIN
VPP
VOUT+
VOUT–
OVZero
CurrLim
CurrLimZero
OVFeedback
CurrSense
GND
VEE
VBOOST
Vout+
Vout–
+5V
–5V
–2.5V
500mV
LOAD SWITCH (OFF BOARD)
CON2
OUTPUT (BINDING POSTS)
+
–
D13 1N4148
A
K
FEEDBACK LK2
(FOR VR1 MOUNTED OFF-BOARD)
CON5
ADJUST OUTPUT VOLTS
VR1 10k
100pF
470Ω
REG4 LM285Z –2.5
VR3 500Ω
SET MAXIMUM VOLTAGE
2.2k
1.8k
SET ZERO OUTPUT VOLTS
ZERO CURRENT LIMIT
VR4 500Ω
VR6 500Ω
(FOR VR2 MOUNTED OFF-BOARD)
CON6
9.1k
SET MAX CURRENT
VR5 500Ω
820Ω
SET CURRENT LIMIT
VR2 10k
100nF
CON4 TO AMMETER
POW+
POW–
SIG–
SIG+
CON3 TO VOLTMETER
10M
1M
VR7 500Ω
TRIM VOLTMETER
S2
910k
VIEW CURRENT LIMIT
VR8 20k
TRIM AMMETER
100k
680Ω
LM79L05
IN
OUT
GND
LM285Z-2.5
A K
NC
BUK9Y6R0
S S S G
D (MTG BASE)
IPP230N06L3 OR IRF1405
G
D
S
LM2940CT-12, 7805
BC327,BC337
B
E
C
1N5819
1N4148
ZD1, ZD2, ZD5-ZD9
SK1545

times with an input current of around 8A (100W / 12V), while their design is for a maximum boost of 12V / 5V = 2.4 times with an input current of around 8A (36W / 5V).

We are using 45V 15A Schottky diodes for D1 and D2 since these are the components in the switchmode section which dissipate the most power. They are relatively compact devices, which is important because the PCB layout of this section is critical.

The BUK9Y6R0-60E MOSFETs were chosen due to their low gate charge (minimising switching losses), low on-resistance (minimising I^2R power dissipation) and ease of soldering. While the LM5118 data sheet says a snubber is not required, we have fitted one – consisting of a 10Ω resistor and 10nF capacitor in series, across D1 –



The PCB assembly is designed to mate with integral pillars inside the half 1U rack plastic case. Part 2 next month has the full assembly details. Note that the final board will differ slightly from this prototype.

to reduce voltage spikes and thus EMI during MOSFET switching.

A parallel array of eight 10µF 25V multi-layer ceramic capacitors is used for input supply filtering. This arrangement has a very low ESR and is also relatively cheap. A similar arrangement of nine 4.7µF 50V ceramic capacitors is used for the output, where low ESR is important to minimise ripple. These form a low-pass filter in combination with inductor L1. A couple of 47µF low-ESR electrolytics are paralleled for ‘bulk capacitance’, which helps switchmode feedback loop stability.

The output of the switchmode regulator passes through another LC low-pass filter, consisting of a 3.3µH bobbin inductor (chosen for its low losses and low price) followed by a 220µF low-ESR electrolytic capacitor. This attenuates the output ripple of the switchmode regulator and this voltage then feeds into the linear regulator (to be described next month).

Feedback and control circuitry

Pin 1 of IC1 is the supply input for its high-side and this is decoupled with a 100nF ceramic capacitor close to that pin of the IC. The resistive divider connected to pin 2 sets the under-voltage lock-out threshold at 11.3V [1.23V × (82kΩ + 10kΩ) / 10kΩ]; while the IC can run from at little as 5V, we want to avoid excessive input current draw at low supply voltages.

The 100nF capacitor at pin 2 sets up the ‘hiccup’ over-current protection; if a prolonged over-current condition is detected, pin 2 is pulled to ground and this capacitor takes some time to charge to the 11.3V threshold, preventing excessive current draw in case of a prolonged short or other overload.

A resistor from pin 3 to ground sets the operating frequency of the switchmode regulator, with 15kΩ giving operation at around 350kHz. Higher frequencies mean less RMS ripple voltage at the output but in exchange for that, switching losses are higher (due to more frequent transitions at the output). Also, inductors tend to be lossier at higher frequencies.

Pin 4 is the enable input and must be pulled high for the regulator to operate. This is connected to power switch S1 via link LK1, with a 100kΩ pull-down resistor. Thus, when power switch S1 is off, voltage is still applied to the input of IC1 but it is disabled so the output is at 0V. This avoids S1 having to switch a high current. LK1 is used to disable and bypass the switchmode regulator for testing the rest of the circuit independently.

The capacitor connected from pin 5 to ground sets the time constant for the ‘emulated ramp compensation’. This value is chosen to match the time constant for the rate of change of current flow through the output inductor (L1) and allows the IC to perform ramp compensation without needing to measure the current through L2. Ramp compensation is required for feedback loop stability at higher duty cycles.

In brief, ramp compensation involves feeding back a voltage related to the output duty cycle to the input of the error amplifier, in order to avoid the duty cycle oscillating either side of the required stable value without settling down.

Pin 6 is the analogue ground pin, ie, the ground return for the components connected to pins 1-9. Pin 7 is the soft start pin and the connected capacitor is charged at power-on, with the output duty cycle being limited until it is fully charged, to prevent the IC from drawing very high input currents while the output capacitor bank is charged.

Pin 8 is for voltage feedback and is the input to the error amplifier. When pin 8 is below 1.23V, the output duty cycle increases and if it is above 1.23V, the output duty cycle is reduced. Normally this is connected to the output of the regulator via a resistive divider, to set a fixed output voltage, or with one resistor replaced by a rheostat or potentiometer to give an adjustable output voltage.

But in this case, we don’t want to set the output voltage of the switchmode regulator directly. Instead, we want its output to be slightly higher than that of the linear regulator, so that it has ‘headroom’ to operate and deal with load transients but without dissipating much power in the linear pass element.

This is achieved using PNP transistors Q4 and Q5. These form a current mirror and their emitters are tied to the output of the switchmode regulator. The difference between this and the output of the linear regulator causes a current to flow through the 680Ω resistor at Q5’s collector. When

the difference is 0.75V, that current is (0.75V – 0.5V) / 680Ω = 0.37mA.

Being a current mirror, this also flows through the 3.3kΩ resistor at the collector of Q4 which gives a voltage of 3.3kΩ × 0.37mA = 1.23V, which is IC1's internal reference voltage level. Thus, its negative feedback will maintain the switchmode output voltage about 0.75V above the linear regulator's output voltage. Being effectively a common-base amplifier, this arrangement has very little phase shift and thus does not affect IC1's feedback loop stability.

Note, though, that the output of the switchmode regulator can't drop below 1.23V as this is the minimum, so dissipation in the linear regulator will be a little higher when its output voltage is below 0.5V or so.

ZD7 and ZD8 prevent the output of the switchmode regulator from exceeding 45V in case of a feedback fault. The 10kΩ current-limiting resistor in combination with zener diode ZD9 and Schottky diode D19 protect the feedback input (pin 8 of IC1) from going outside the range of –0.3 to 5V, which would risk destroying the IC.

Diode D18 protects Q4 and Q5 from damage due to base-emitter junction reverse breakdown.

Linear regulator supply rails

The linear regulator requires a positive supply rail (V_{PP}) that is at least 7V above the output in order to switch its internal MOSFET on fully to supply a high load current. It also requires a well-filtered negative rail (V_{EE}) several volts below ground so that it can turn that MOSFET fully off when required (allowing for the voltage drop of several internal driving transistors).

These are supplied from a charge pump shown in Fig.3. This is based on REG1, a 12V low-dropout regulator and IC2, a 7555 CMOS timer IC. IC2 is set up to provide a 12V square wave at 100kHz at its output pin 3. This drives a complementary pair of bipolar transistors, Q6 and Q7, which form an inverting buffer. The 100pF capacitors across their base current-limiting resistors speed up switch-off to prevent cross-conduction.

The buffered output drives two 1µF capacitors, one of which is charged to the switchmode output voltage by D5 and the other which is clamped to ground by D3. When the buffered output of Q6/Q7 goes positive, D6 becomes forward biased and the connected 100µF capacitor is charged to roughly 10V above the switchmode supply rail. Similarly, when the collectors of Q6/Q7 go negative (to ground), D4 becomes forward biased, charging the connected 100µF capacitor to about –10V.

These two new voltage rails are then filtered using RC filters (10Ω/220µF and 10Ω/100µF respectively) to remove most of the 100kHz component, forming relatively smooth DC supply rails. The –10V rail is then regulated by REG3 to a stable and clean –5V for the linear regulator's V_{EE} rail. This regulation is necessary for two reasons: (1) any noise or ripple on this line will affect the regulator's output; and (2) this is also used as the reference for setting the output voltage.

Adjustments and trimming

As stated earlier, the linear regulator acts to keep the feedback voltage at around 0V. This is determined by the output voltage in combination with the position of 10kΩ potentiometer VR1 (Fig.3). This can be a 10-turn potentiometer to give finer output adjustment. It acts as a voltage divider in combination with trimpot VR3 and the 470Ω resistor connecting them.

VR3 is connected to a –2.5V rail, derived from the –5V rail by voltage reference REG4. The circuit will operate without REG4 – however, it will be subject to output voltage variations due to thermal drift in –5V regulator REG3; REG4 has much better thermal stability and is not dissipating anywhere near as much power either (typically <1mW compared to ~100mW for REG2).

When VR1 is at minimum resistance, the output rail is effectively connected directly to the feedback point and so the output voltage is at 0V. As VR1 is turned clockwise and its resistance increases, the output voltage must increase in order to keep the feedback voltage at 0V. For example, when the resistance of VR1 is around 625Ω, matching that of VR3 plus the 470Ω series resistor, the output is at around 2.5V.

VR3 is used to trim out variations in the other components, giving 40V at the output with VR1 fully clockwise.

The output voltage is fed to VR1 via link LK2 in parallel with diode D13. This is intended to allow for some wiring voltage drop compensation to be used due to the need to run a wire from the output terminal to the off-board load switch, in which case LK2 is removed and a wire is run from the supply side of the load switch to the lower terminal of LK2. In case this connection fails, D13 limits the output voltage from rising more than 0.6V.

The current limit is set using VR2, another 10kΩ potentiometer which can also be a 10-turn type. Its wiper voltage is filtered with a 100nF capacitor and fed into the linear regulator where it is compared with the voltage across a 100mΩ shunt. There is 500mV across VR2, derived from the +5V rail by trimpot VR5. This +5V comes from linear regulator REG2, which supplies several reference voltages but also the power for the two panel meters.

The voltmeter reads the voltage across the output terminals, but this is a 200mV full-scale meter so the output voltage is divided down by 1MΩ and 1kΩ resistors plus 500Ω trimpot VR7 for fine tuning. The panel meter's input impedance is 100MΩ so we are using relatively high value resistors here.

Similarly, to get a reading of up to 5A on the ammeter panel, we need a 0-50mV signal and so the 0-500mV from the shunt (at CurrSense) is divided down by a factor of 10 by a 910kΩ resistor, 100kΩ+1kΩ resistors and 20kΩ trimpot VR8. S2 allows the voltage feeding this divider to be switched from the current feedback to the current-limit setting, so that the limit can be viewed without having to short the output terminals.

The 10MΩ and 2.2MΩ resistors provide a small bias current to the two panel meters so that they do not give a negative reading when the output voltage is 0V or no current is being drawn.

The two remaining trimpots, VR4 and VR6, are used to trim out any offset error in the voltage feedback and current-limiting circuitry respectively. These inputs have a low impedance to ground so the adjustment ranges span just a few millivolts either side of 0V.

Remaining circuitry

The circuit is protected from a reversed input supply polarity by MOSFET Q1. When the supply is connected the right way, Q1's gate is pulled positive by the 100kΩ resistor and clamped at a safe level by the 15V zener diode. This switches it on and allows ground current to flow from the circuit back to the supply.

If connected backwards, the gate is pulled negative and so Q1 remains off. Its body diode is also reverse-biased and thus very little current will flow. The 100nF capacitor from its gate to ground slows its turn-on to avoid large current spikes charging the input capacitor bank when power is first supplied; IC1 has a soft-start feature, so it's just this input bank that can draw a high current initially.

A 10A fuse protects the circuit against serious faults, and 27V zener diode ZD2 conducts if the input supply voltage becomes too high. If that excessive voltage is maintained for very long, it will blow the fuse. The clamping voltage is above the 25V rating of the input capacitor bank, but they are unlikely to fail due to a brief over-voltage of just a few volts and we don't want ZD2 to conduct any significant current with the supply below 25V.

A 4.7µF capacitor and 3.3µH inductor (L2) prevent much switching noise from passing back through the input leads, which could lead to electromagnetic interference being radiated from them. Power switch S1 enables the switchmode regulator and at the same time, applies power to the rest of the circuit.

When LK1 is moved to the 'Test' position, the linear regulator remains off and power can bypass it from S1 straight to the output. This is so that the constructor can check the linear regulator and other circuitry is working before activating the switchmode portion; otherwise troubleshooting could be very difficult.

Finally, there is a Schottky clamp diode (D16) at the output of the switchmode regulator so that its output can not be pulled very far below ground by the linear regulator at start-up. There is also a clamp consisting of two 27V zeners (ZD5 and ZD6) in series after filter inductor L3, so that if the switchmode regulator feedback fails (including the ZD7/ZD8 voltage clamp), its output will not go high enough to damage the 63V filter capacitors or any part of the linear regulator circuitry.

LDO operation and construction

That's all we have room for this month. Next month, we'll describe the linear regulator section and begin the construction.

HP 34401A Digital
Multimeter 6 ½ Digit

HP 54600B Oscilloscope Analoque/Digital
Dual Trace 100MHZ

MARCONI 2955B Radio
Communications Test Set

FLUKE/PHILIPS PM3092 Oscilloscope
2+2 Channel 200MHZ Delay TB, Autoset etc

LAMBDA GENESYS	PSU GEN100-15 100V 15A Boxed As New	£325
LAMBDA GENESYS	PSU GEN50-30 50V 30A	£325
HP34401A	Digital Multimeter 6.5 digit	£275-£325
HP33120A	Function Generator 100 microHZ-15MHZ	£260-£300
HP53131A	Universal Counter 3GHZ Boxed unused	£500
HP53131A	Universal Counter 225MHZ	£350
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IFR 2025	Signal Generator 9kHz - 2.51GHZ Opt 04/11	£900
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R&S APN62	Syn Function Generator 1HZ-260KHZ	£195
Fluke/Philips PM3092	Oscilloscope 2+2 Channel 200MHZ Delay etc	£250
HP3325A	Synthesised Function Generator	£195
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HP6032A	PSU 0-60V 0-50A 1000W	£750
HP6622A	PSU 0-20V 4A Twice or 0-50V 2A Twice	£350
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HP6644A	PSU 0-60V 3.5A	£400
HP6654A	PSU 0-60V 0-9A	£500
HP8341A	Synthesised Sweep Generator 10MHZ-20GHZ	£2,000
HP83731A	Synthesised Signal Generator 1-20GHZ	£1,800
HP8484A	Power Sensor 0.01-18GHZ 3nW-10uW	£75
HP8560A	Spectrum Analyser Synthesised 50HZ - 2.9GHZ	£1,250
HP8560E	Spectrum Analyser Synthesised 30HZ - 2.9GHZ	£1,750
HP8563A	Spectrum Analyser Synthesised 9KHZ-22GHZ	£2,250
HP8566B	Spectrum Analsyer 100HZ-22GHZ	£1,200
HP8662A	RF Generator 10KHZ - 1280MHZ	£750
Marconi 2022E	Synthesised AM/FM Signal Generator 10KHZ-1.01GHZ	£325
Marconi 2024	Synthesised Signal Generator 9KHZ-2.4GHZ	£800
Marconi 2030	Synthesised Signal Generator 10KHZ-1.35GHZ	£750
Marconi 2305	Modulation Meter	£250
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Marconi 2945	Communications Test Set Various Options	£2,500
Marconi 2955	Radio Communications Test Set	£595
Marconi 2955A	Radio Communications Test Set	£725
Marconi 6200	Microwave Test Set	£1,500
Marconi 6200A	Microwave Test Set 10MHZ-20GHZ	£1,950
Marconi 6200B	Microwave Test Set	£2,300
Marconi 6960B with	6910 Power Meter	£295

Tektronix TDS3012	Oscilloscope 2 Channel 100MHZ 1.25GS/S	£450
Tektronix 2430A	Oscilloscope Dual Trace 150MHZ 100MS/S	£350
Tektronix 2465B	Oscilloscope 4 Channel 400MHZ	£600
Cirrus CL254	Sound Level Meter with Calibrator	£40
Farnell AP60/50	PSU 0-60V 0-50A 1KW Switch Mode	£195
Farnell H60/50	PSU 0-60V 0-50A	£500
Farnell B30/10	PSU 30V 10A Variable No Meters	£45
Farnell B30/20	PSU 30V 20A Variable No Meters	£75
Farnell XA35/2T	PSU 0-35V 0-2A Twice Digital	£75
Farnell LF1	Sine/sq Oscillator 10HZ-1MHZ	£45
Racal 1991	Counter/Timer 160MHZ 9 Digit	£150
Racal 2101	Counter 20GHZ LED	£295
Racal 9300	True RMS Millivoltmeter 5HZ-20MHZ etc	£45
Racal 9300B	As 9300	£75
Black Star Orion	Colour Bar Generator RGB & Video	£30
Black Star 1325	Counter Timer 1.3GHZ	£60
Ferrograph RTS2	Test Set	£50
Fluke 97	Scopemeter 2 Channel 50MHZ 25MS/S	£75
Fluke 99B	Scopemeter 2 Channel 100MHZ 5GS/S	£125
Gigatronics 7100	Synthesised Signal Generator 10MHZ-20GHZ	£1,950
Panasonic VP7705A	Wow & Flutter Meter	£60
Panasonic VP8401B	TV Signal Generator Multi Outputs	£75
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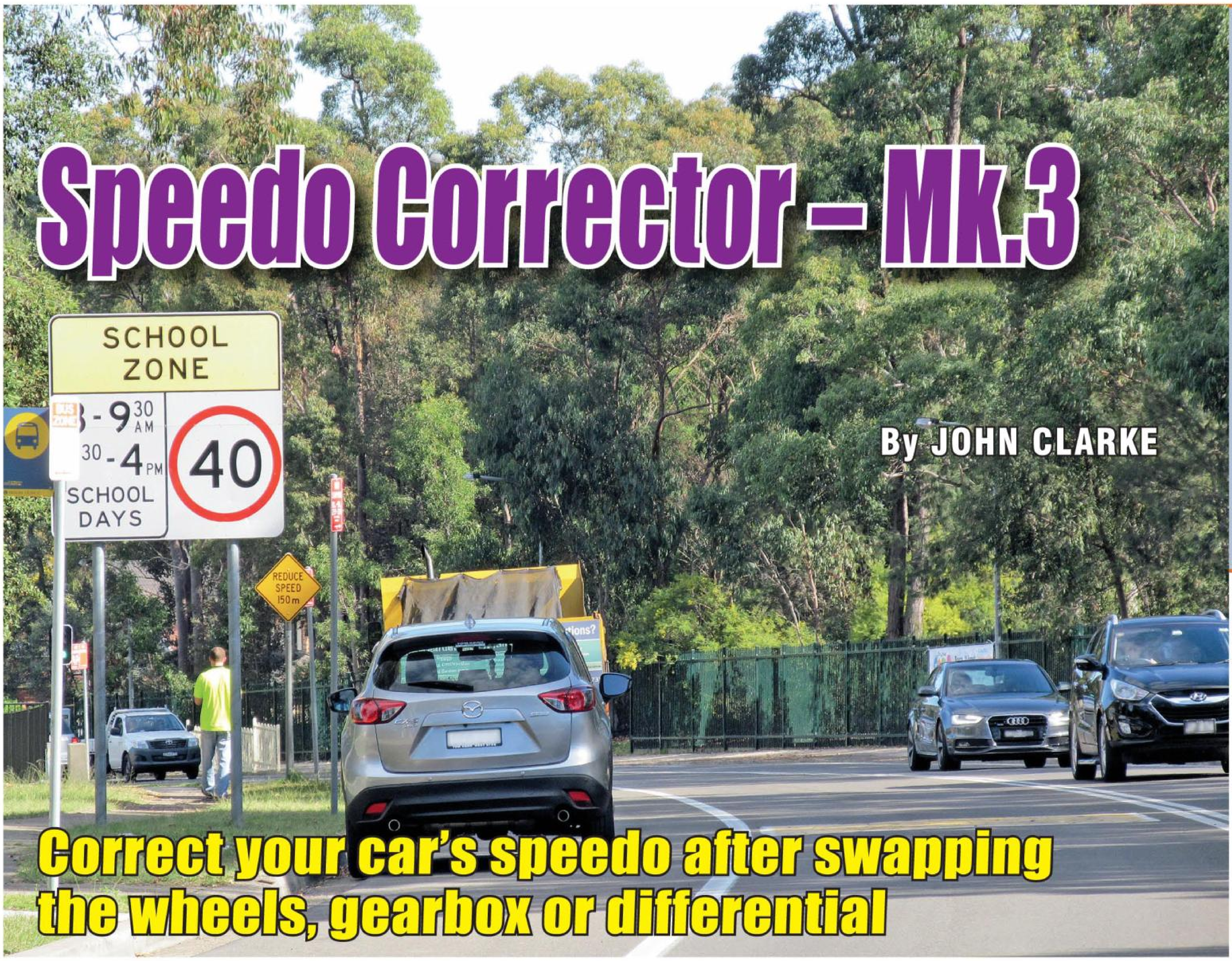


Speedo Corrector – Mk.3

By JOHN CLARKE

Correct your car's speedo after swapping the wheels, gearbox or differential

If you have swapped your car's instrument panel, gearbox or differential with one from a different vehicle, your speedometer and odometer may no longer be correct. The same thing applies if you have fitted wheels or tyres with a different diameter. The solution is to use our updated *Speedo Corrector* which can increase or decrease the indicated speedometer reading. It operates from 12V or 24V DC and is simple to set up.

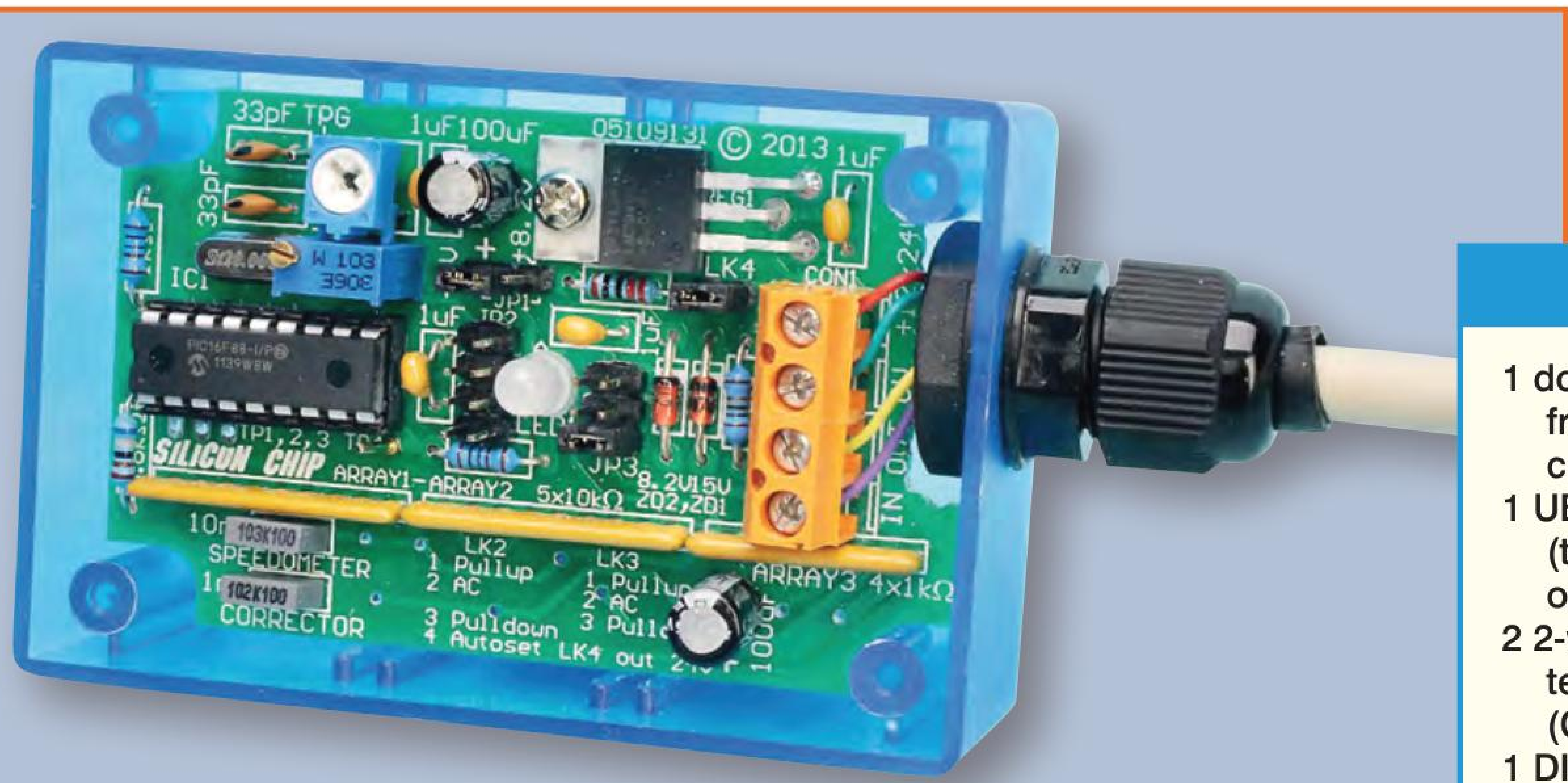
IF YOU HAVE made any of the aforementioned modifications to your vehicle, you will almost certainly need to correct the speedometer and odometer readings.

The *Speedo Corrector* can adjust your vehicle's speedometer to show the correct road speed. It will work with analogue or digital speedometers that use a frequency signal for speed sensing. It will not work with older speedometers that use a mechanical cable unless you make a new speed pick-up with a Hall effect sensor and magnets on a driveshaft. Nor will it work with some of the latest vehicles that have speedometers that connect to the Controller Area Network (CAN) bus instead of using a dedicated speedometer signal. CAN bus is a communications system between sensors and instruments in the vehicle.

The *Speedo Corrector* intercepts the signal from the speed sensor and then increases or reduces its frequency before it is applied to the speedometer. Note that the *Speedo Corrector* will

Main features

- Allows alteration of speedo reading so it reads faster/slower over wide range
- Caters for three input signal types
- Automatic or manual set-up of input signal type
- LED indication of valid speed sensor signal being received during set up
- 12V or 24V operation (set using a link)
- Adjustable response rate to compensate for speedo lag
- LED and output voltage rate adjustment indication



The compact PCB assembly clips into a UB5 plastic utility box. An on-board trimpot allows its output pulse frequency to be adjusted so that the car's speedo matches the speed read-out on a GPS.

not correct for non-linearities in the speedometer, but fortunately most speedometers are proportional in the region of 40-100km/h and so correction at one speed in this region should provide the correct speed reading at other speeds.

You will need to be able to access the speedometer signal in your vehicle to be able to install the *Speedo Corrector*. This may require disassembly of the dashboard or steering column (see below).

Optimistic readings

With most unmodified vehicles running with standard sized tyres, the speedometer will tend to read optimistically, showing a higher than actual speed. So a speedometer indication of 100km/h could mean you are actually travelling between 87.27km/h and 100km/h, depending on the particular speedometer's accuracy.

UK speedo standards

According to **www.thecarexpert.co.uk/how-accurate-is-a-car-speedometer/** the UK law is based on the EU standard, with some minor changes. It states that a speedo must never show less than the actual speed, and must never show more than 110% of actual speed + 6.25mph. So if your true speed is 40mph, your speedo could legally be reading up to 50.25mph but never less than 40mph. Or to put it another way, if your speedo is reading 50mph, you won't be doing more than 50mph, but it's possible you might actually only be travelling at 40mph.

Both the speedometer and odometer use the same speed signal that's taken either from a sensor in the gearbox or a wheel sensor that is also used for the anti-lock braking system (ABS). The common signal for both speedo and odometer means that altering the sensor signal will change both the odometer and speedometer readings.

A speedometer is typically less accurate than the odometer but the *Speedo Corrector Mk.3* (ideally) should be calibrated for both to be within UK law. A GPS speedometer can be used as a guide to the correct speed adjustment while roadside odometer check signs can verify the odometer accuracy.

The *Speedo Corrector Mk.3* is a major revision of the *Speedo Corrector* published in the September 2008 issue of *EPE*. This new version is considerably smaller, making it easier to install in a vehicle. It now operates from 12V or 24V and includes the original features such as automatic or manual set-up to suit the speed signal sensor and an AC signal output to suit Nissan speedometers. The overall adjustment range has also been increased over the original.

And instead of using two expensive rotary switches (as in the 2006 version) to set the adjustment, we now use a low-cost multi-turn trimpot. A bi-coloured LED shows green for adjustments that increase the output frequency and red when the output frequency is reduced (with respect to the input signal). A test point is provided to allow a multimeter to monitor the amount of adjustment that's set.

In practice though, it is usually not necessary to monitor the degree of adjustment. The relevant trimpot (VR1) is simply adjusted so that the

Parts List

1 double-sided PCB, available from *EPE PCB Service*, coded 05109131, 78 × 46mm
1 UB5 box, 83 × 54 × 31mm (translucent blue, clear, black or grey)
2 2-way PCB-mount screw terminal blocks, 5.08mm pitch (CON1)
1 DIL18 IC socket
1 7 × 2 DIL pin header (2.54mm pitch) broken into 4-way and 3-way headers (JP2,JP3)
1 5-pin SIL header (2.54mm pitch) broken into 3-way and 2-way headers (JP1,LK4)
1 10kΩ 20-turn top-adjust trimpot (VR1)
1 10kΩ miniature horizontal mount trimpot (VR2)
5 jumper shunts
1 20MHz crystal (X1)
1 M3 × 10mm screw
1 M3 nut, shakeproof washer

Semiconductors
1 PIC16F88-E/P microcontroller programmed with 0510913A.hex (IC1)
1 LM2940CT-5 TO-220 5V low dropout regulator (REG1)
4 BC846 (SOT23) NPN SMD transistors (Q1,Q2,Q3,Q5)
2 BC857 (SOT23) PNP SMD transistors (Q3,Q6)
1 15V 1W zener diode (ZD1)
1 8.2V 1W zener diode (ZD2)
1 bi-colour (red/green) 3mm or 5mm LED (LED1)
2 PC stakes (TPG and TP4)

Capacitors
2 100μF 16V PC electrolytic
3 1μF monolithic multi-layer ceramic (MMC)
1 10nF MKT
1 1nF MKT
2 33pF NP0 ceramic

Resistors (0.25W, 1%)
1 6.8kΩ
2 1kΩ
1 220Ω 0.5W
1 10Ω

Resistor arrays
2 5-way 10kΩ resistor arrays (4610X-102-103LF)
1 4-way 1kΩ resistor array (4608-102-102LF)

Specifications

Output ratio: adjustable from 1 to 1/6 the rate for lower output frequencies and from 1 to 6 times for higher frequencies.

Adjustment resolution: < 0.4% for 1x to 2x and 1x to ½x adjustments; < 0.8% for 2x to 4x and ½x to ¼x; < 1.8% to x6 and x1/6

Minimum input or output operating frequency: 1Hz.

Maximum input and output frequency to maintain maximum adjustment resolution: 1.2kHz.

Response rate adjustments: 1s (fully anticlockwise), 500ms, 250ms (mid setting), 125ms and 62.5ms (fully clockwise) – set using VR2.

Input and output types: pull-up, pull-down or AC.

Output swing: 0-8.2V or 0-5V or 8.2V peak-peak AC or 5V peak-peak AC.

Maximum input voltage: 50V RMS.

Minimum input sensitivity: 0.7V peak (on high-sensitivity setting); 2.5V peak (on low-sensitivity setting).

Power: 9-30V DC at 25mA.

speedometer or odometer reads correctly, compared with a GPS speedo or roadside odometer check markers (at 1km intervals).

The *Speedo Corrector* is housed in a small plastic case measuring 82 × 53 × 30mm. It can be concealed anywhere underneath the dashboard.

Circuit description

Fig.1 shows the circuit which is based on IC1, a PIC16F88-E/P microcontroller. It's programmed to alter the incoming speed signal frequency by a factor set using trimpot VR1.

Transistors Q2, Q3 and Q4 are included to provide for speedometer sensors that require pull-up or pull-down resistors. Q3 and Q4 are turned on by RA4 (pin 3) to provide pull-up via a 1kΩ resistor or Q2 is turned on by RA3 (pin 2) to pull the same resistor down, or all the transistors are left turned off if no pull-up or pull-down is required (in the case of an AC sensor).

Mechanical Speedo?

The *Speedo Corrector Mk.3* will work only on electronic speedometers, ie, those that don't have a mechanical rotating cable driving them. If you have an older car with a mechanical speedo, then you won't be able to correct it – at least not using this circuit.

Non-linearity?

The *Speedo Corrector Mk.3* will not compensate for non-linear errors. In other words, if the speedo reads 10% high at 25km/h and 4% high at 100km/h, you won't be able to use the *Speedo Corrector Mk.3* to get the speedo accurate at all speeds.

However, most speedo errors are proportional and so can be dialled-out with the *Speedo Corrector Mk.3.*

Whether or not Q2, Q3 and Q4 are turned on is controlled by IC1 in response to the links for JP2, connected to its RB2, RB4, RB5 and RB7 pins (8, 10, 11 and 13).

As well as providing options for pull-up and pull-down, there is an 'Autoset' mode whereby the *Speedo Corrector* software will select each setting one at a time until the micro gets a satisfactory signal. With each selection, the program waits to check if it receives at least 20 cycles of signal within a one-second period. If not, it moves on to the next selection. When it does receive a signal, that input selection is stored in memory and used thereafter.

Manual selection via the jumper links is provided for installers of the unit who already know the required input condition for particular vehicles. Manual selection can also be used should the automatic Autoset not work successfully on your vehicle.

All the resistors on the circuit marked with an asterisk (*) are in resistor arrays: two 10-pin arrays comprising five 10kΩ resistors in each and a single 8-pin array comprising four 1kΩ resistors. The arrays save space on the PCB.

After being pulled high, low or neither, the input signal is fed to the base of Q1 via a low-pass filter consisting of a 10kΩ resistor and 10nF capacitor and then via another 10kΩ resistor. A 6.8kΩ resistor at the base of Q1 can be either connected to 0V or left floating under the control of the RA2 output of IC1. When floating, Q1 will be switched on with a 0.7V input signal, corresponding to the high-sensitivity setting. When the 6.8kΩ resistor is connected to 0V, the signal level required to switch Q1 is increased to about 2.5V (the low sensitivity setting).

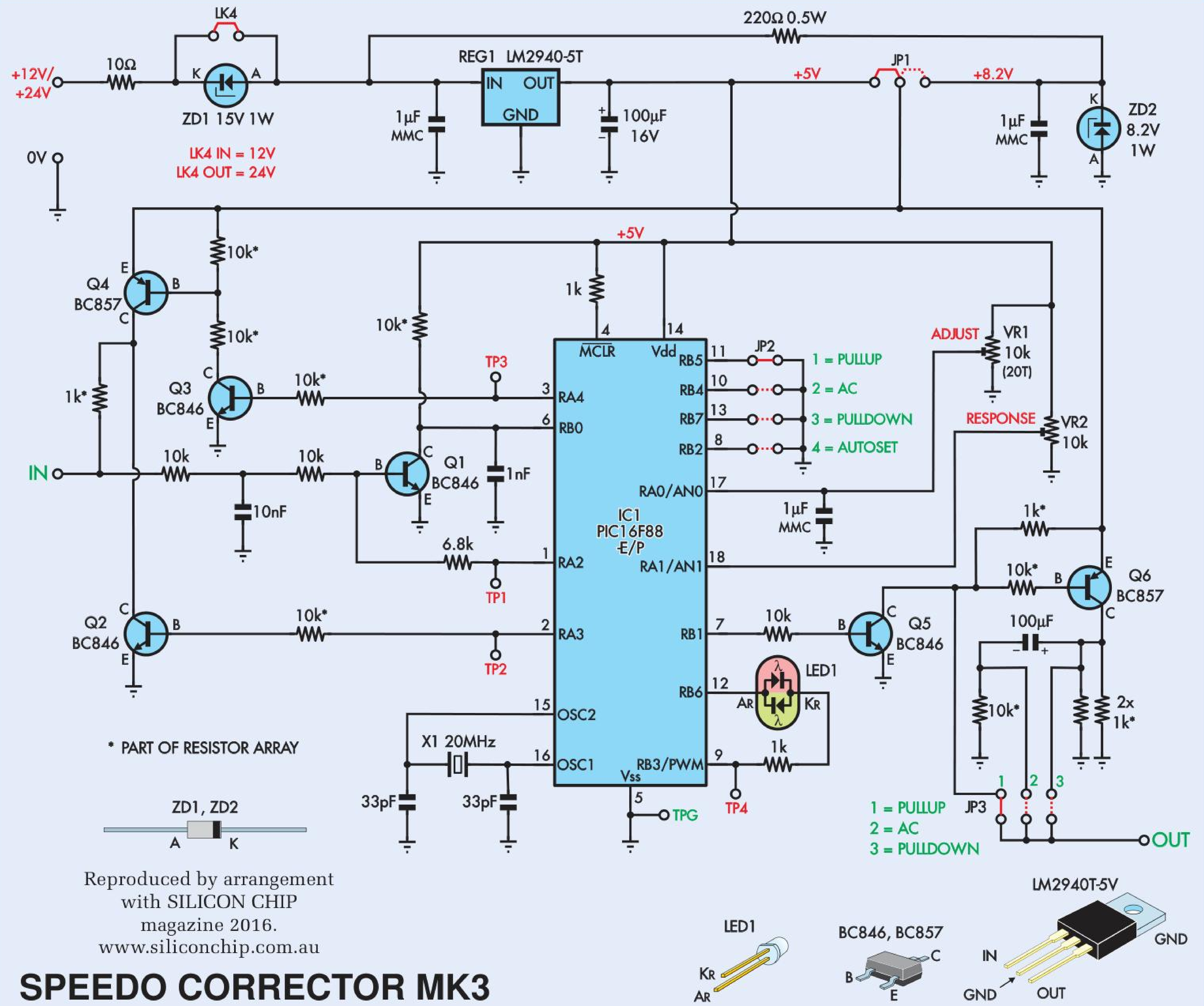
The signal at Q1's collector is filtered with a 1nF capacitor and fed to the RB0 input, pin 6, of IC1. This has an internal Schmitt trigger to ensure a clean signal. The microcontroller then increases or decreases the signal frequency according to the program and feeds it out from its RB1 output at pin 7 to the base of transistor Q5. Q5's collector load is a 1kΩ resistor connected to the +8.2V or +5V supply, as selected by link JP1. Q5 drives Q6, which has two paralleled 1kΩ resistors (in the 8-pin resistor array, mentioned above). This is done to provide a relatively low impedance pull-down output.

Links at JP3 provide the options for pull-down, pull-up or AC-coupling for the output signal. Note that the pull-up signal comes from the collector of Q5, while the pull-down or AC signal comes from the collector of Q6.

VR1 is used to set the degree of speedometer correction. The voltage at VR1's wiper is applied to the AN0 input of IC1 and is converted to a 9-bit digital value. With the wiper centred, the speed signal passes through unchanged. Winding the trimpot clockwise increases the signal frequency, while winding it anti-clockwise reduces the frequency.

The bi-coloured LED (LED1) connected between pins 9 and 12 indicates frequency increase or decrease, as previously mentioned. When VR1 is set at mid-setting, both the red and green sections are driven equally and the resulting orange colour indicates 'no change' in output frequency, corresponding to a 50% duty cycle of the 19kHz pulse width modulation (PWM) signal at pin 9. At the same time, the voltage at test point TP4 will be at 2.5V.

For other settings of VR1, the RB6 output at pin 12 will be either low or high; low for green and high for red. The LED brightness will vary slightly with the PWM duty cycle, but this is not sufficient to gauge the degree of adjustment off centre for VR1.


LK4
10Ω
+12V/
+24V
0V
ZD1 15V 1W
K
A
LK4 IN = 12V
LK4 OUT = 24V
220Ω 0.5W
REG1 LM2940-5T
IN
OUT
GND
1µF
MMC
100µF
16V
+5V
JP1
+8.2V
ZD2
8.2V
1W
Q4
BC857
Q3
BC846
Q2
BC846
Q1
BC846
10k*
1k*
IN
10k
10nF
6.8k
1nF
1k
TP1
TP2
TP3
TP4
TPG
4
MCLR
14
Vdd
3
RA4
6
RB0
1
RA2
2
RA3
15
OSC2
16
OSC1
5
Vss
IC1
PIC16F88
-E/P
RB5
RB4
RB7
RB2
RA0/AN0
RA1/AN1
RB1
RB6
RB3/PWM
JP2
1 = PULLUP
2 = AC
3 = PULLDOWN
4 = AUTOSET
ADJUST
VR1
10k
(20T)
RESPONSE
VR2
10k
Q5
BC846
Q6
BC857
LED1
AR
KR
X1 20MHz
33pF
100µF
2x
1k*
JP3
1 = PULLUP
2 = AC
3 = PULLDOWN
OUT
* PART OF RESISTOR ARRAY
ZD1, ZD2
BC846, BC857
B
C
E
LM2940T-5V
GND

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SPEEDO CORRECTOR MK3

Fig.1: the circuit is based on PIC microcontroller IC1. It takes the speedo signal and multiplies it according to the setting of trimpot VR1. The speedo signal frequency can be either increased or decreased.

Setting speedometer response

Different speedos respond at different rates to a change in the signal frequency. The *Speedo Corrector Mk.3* can compensate for this by varying its response period which can be adjusted from between 1s and 62.5ms. The required setting used depends on the response of the speedometer when the vehicle comes to a stop. If the speedometer takes too long to drop back to zero with a one-second response, then it should be reduced with trimpot VR2.

IC1 operates at 20MHz using crystal X1. This frequency was chosen so that the software program runs sufficiently fast to operate with speedometer signals up to 1.2kHz. Note that the *Speedo Corrector Mk.3* will operate with signals above 1.2kHz, but the accuracy of correction will be reduced.

An internal power-on reset for IC1 is provided using the MCLR input at pin 4 and is connected to the 5V supply via a 1kΩ resistor. This keeps the IC reset until the power supply voltage is correct.

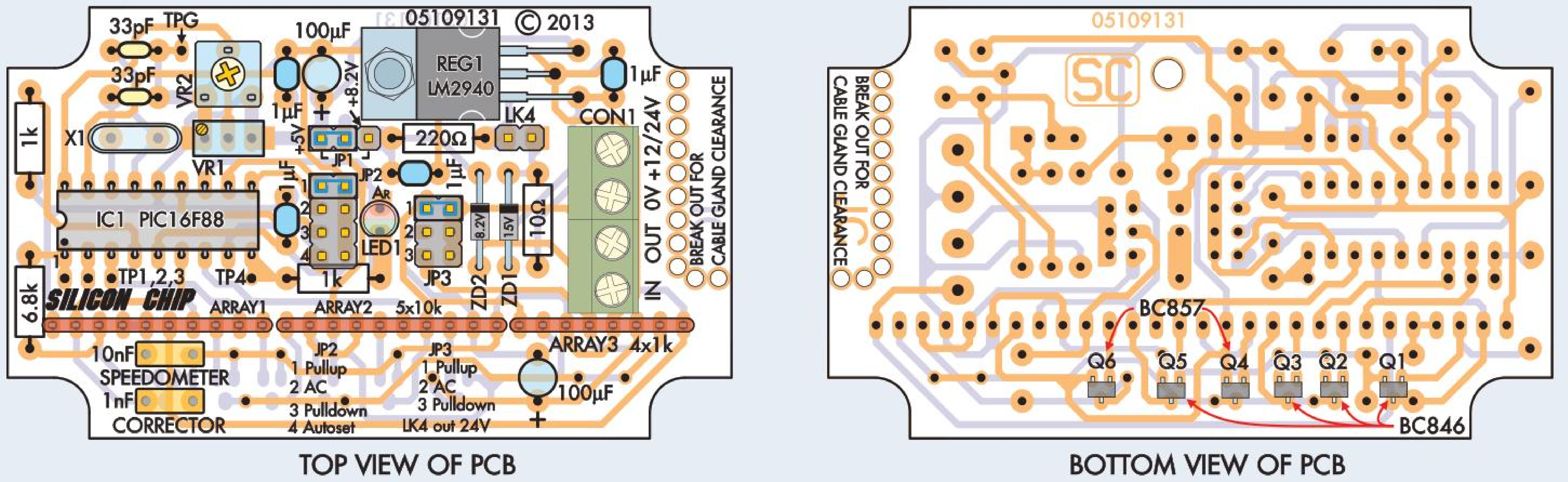
Power for the circuit is applied via a 10Ω resistor and a 15V zener diode (ZD1) to an LM2940-5T 5V automotive regulator, REG1. For 12V operation, ZD1 is shorted out with link LK4. For 24V operation, LK4 is removed and ZD1 effectively subtracts 15V from the supply applied to REG1.

An 8.2V supply is provided using ZD2 and the 220Ω resistor. This supply can be selected to give a higher signal output from the corrector which is necessary for reliable operation with some speedometers.

Construction

The *Speedo Corrector* is built onto a double-sided PCB with plated through holes. This board is available from the *EPE PCB Service*, coded 05109131, measures 78 × 46mm and is designed to clip into a plastic UB5 box measuring 83 × 54 × 31mm.

A hole is made in one end of the box to allow a cable gland to be fitted to allow wire entry (input and output signals plus supply leads). Alternatively, the leads can be run out through a grommet and restrained inside the box using a cable tie.



33pF
TPG
33pF
VR2
100µF
05109131
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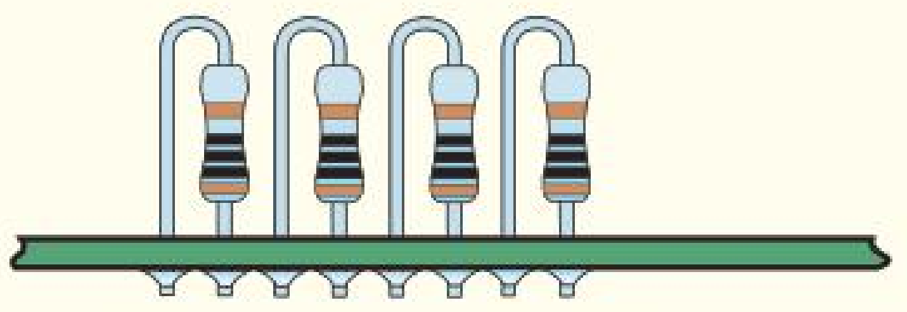
REG1
LM2940
1µF
+8.2V
+5V
1µF
1µF
CON1
LK4
220Ω
JP1
JP2
1k
X1
VR1
IC1 PIC16F88
LED1
A
K
8.2V
15V
10Ω
ZD2
ZD1
IN OUT 0V +12/24V
BREAK OUT FOR CABLE GLAND CLEARANCE
TP1,2,3
TP4
6.8k
SILICON CHIP
ARRAY1
ARRAY2 5x10k
JP3
ARRAY3 4x1k
10nF
SPEEDOMETER
1nF
CORRECTOR
JP2
1 Pullup
2 AC
3 Pulldown
4 Autoset
JP3
1 Pullup
2 AC
3 Pulldown
LK4 out 24V
100µF
05109131
SC
BC857
Q6
Q5
Q4
Q3
Q2
Q1
BC846

TOP VIEW OF PCB

BOTTOM VIEW OF PCB

Fig.2: follow these two diagrams to build the unit, starting with the six SMD transistors (Q1-Q6) on the back of the PCB. Install link LK4 for 12V operation or remove it for 24V operation. The other linking options are explained in the text.



ALTERNATIVE TO RESISTOR ARRAY USING SINGLE RESISTORS

Fig.3: single resistors mounted end-on can be used instead of the resistor arrays. You would need 10 × 10kΩ and 4 × 1kΩ resistors.

If you intend fitting a cable gland, it will be necessary to snap off a breakaway section located at one end of the PCB, to allow space for the cable gland nut inside the box (see photo).

Fig.2 shows the parts layout on the PCB. First, check the PCB for any faults (rare), then start the assembly by installing the six SMD transistors on the underside of the PCB. Note that Q1, Q2 and Q5 are BC846s, while Q4 and Q6 are BC857s, so be careful not to get them mixed up.

You will need a good light (preferably a magnifying lamp) and a fine-tipped soldering iron for this job. The procedure is straightforward: carefully place transistor Q1 in position, hold it down with some tweezers and solder one of its leads first. That done, make sure that it's positioned correctly (remelt the solder and nudge it if necessary) before soldering the other two pins.

Repeat this procedure for the remaining five SMD transistors, taking care to fit the correct type to each location.

Once the SMD devices are all in place, flip the board over and install the single resistors and zener diodes. It's a good idea to check each resistor's value using a digital multimeter before soldering it into position.

Make sure that the zener diodes are installed with the correct polarity, ie, with the banded ends oriented as shown on Fig.2. Don't get these two devices mixed up – ZD1 is a 15V zener, while ZD2 is an 8.2V zener.

There are two PC stakes to be installed – these are at test points TPG and TP4. PC stakes are not installed at TP1, TP2 and TP3, as these test points can be monitored by touching a multimeter probe on the plated PCB pads provided.

Resistor arrays

The resistor arrays are labelled 10X-2-103 (5 × 10kΩ) and 8X-2-102 (4 × 1kΩ). These can be installed now and can go in either way around.

Alternatively, you can use single resistors mounted end-on in place of the arrays, as shown in Fig.3. You would need to install 10 × 10kΩ resistors instead of the two 5-way arrays and 4 × 1kΩ resistors instead of the 4-way array.

The 20MHz crystal (X1) and an 18-pin IC socket for IC1 can be fitted next. The socket must be oriented with its notched end towards the adjacent edge of the PCB. Follow with regulator REG1; it's mounted horizontally and secured with an M3 screw, shakeproof washer and nut. Bend its leads at right angles before installing it and be sure to tighten it's mounting screw before soldering the leads.

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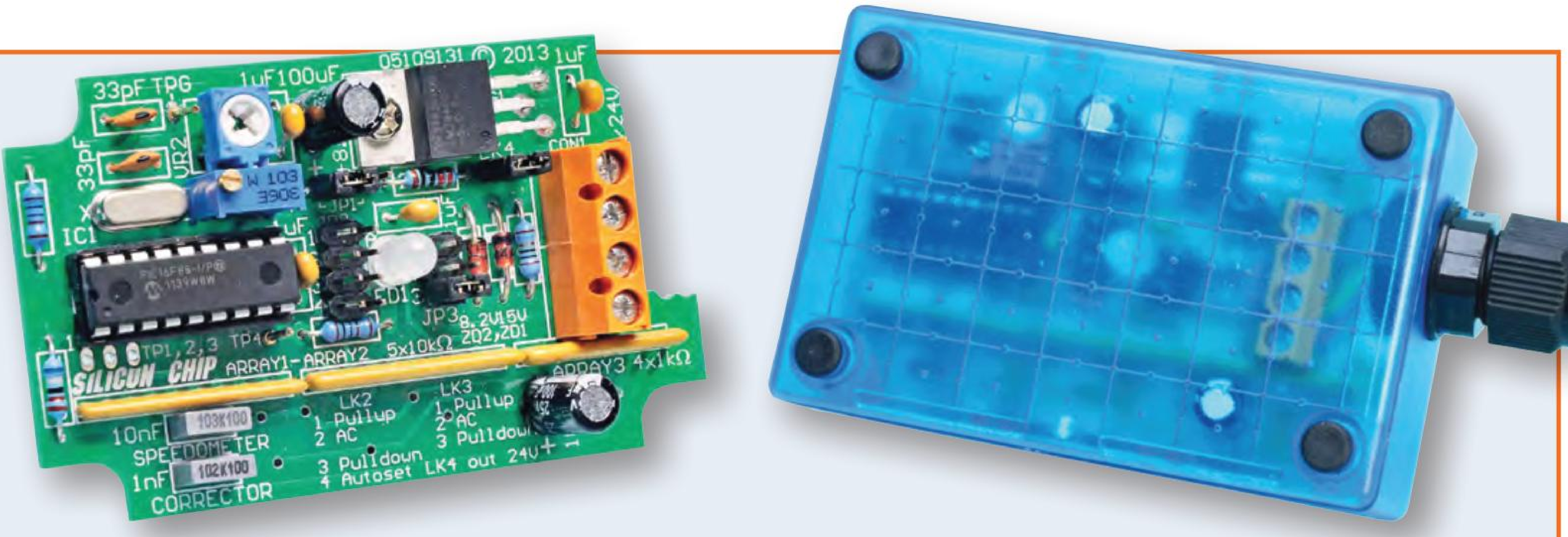


Take care to ensure that microcontroller IC1 and the other polarised parts are oriented correctly and don't get the SMD transistors mixed up. The signal and power leads exit the case through a cable gland, as shown at right.

Don't do this in reverse order. If you solder the leads first, you could crack the PCB tracks as the mounting screw is tightened down.

Now for the capacitors. The ceramic and MKT types can go in either way around, but the 100µF electrolytic must be oriented as shown.

The 4-way and 3-way dual-in-line pin headers for JP2 and JP3 are next. Push them all the way down onto the PCB before soldering their leads.

Indicator LED

LED1 is mounted so that it sits directly on (or very close) to the PCB. Make sure it's oriented correctly with its anode (longer lead) going to the pad marked 'AR'.

That done, install trimpots VR1 and VR2 and the 4-way screw terminal block. VR1 is mounted with its adjusting screw towards the crystal. The 4-way screw terminal block is made by dovetailing two 2-way terminal blocks together. Push it all the way down onto the PCB and make sure its wire entry holes face outwards before soldering the pins.

Initial tests

Before plugging IC1 into its socket, connect a jumper across LK4 and apply 12V to the circuit (ie, between the 12/24V and the 0V input terminals). That done, check that the voltage between pins 5 and 14 of IC1's socket is around 5V (you should get a reading that's between 4.85V and 5.15V).

If this is correct, disconnect the power and plug microcontroller IC1 into its socket, taking care to orient it correctly. Make sure that none of the IC's pins are bent under the socket or splayed down the side during this procedure.

With IC1 now in place, reapply power and adjust VR1 to its mid setting. This is indicated when both the green and red colours in LED1 flash. If the LED is red, rotate VR1 clockwise to reach mid setting. If the LED is green, rotate VR1 anticlockwise until mid-setting is reached.

Installing the jumpers

Before installing the *Speedo Corrector* in your vehicle, you need to fit the relevant jumper links.

First, either leave the jumper on LK4 for 12V operation or remove it for 24V operation. That done, install jumper JP1 in the 5V position, but don't fit a jumper to the JP3 header yet.

Most readers should also install a jumper in position 4 on header JP2 (ie, in the Autoset position) for automatic setting up. The response trimpot (VR2) should initially be set fully anticlockwise for a 1s response time.

In some cases, you may already know the required jumper settings for the vehicle (eg, if you've already installed a *Speedo Corrector Mk.3* in a similar vehicle). In that case, fit a jumper in position 1 of JP2 for pull-up, position 2 for AC or position 3 for pull-down. Low-sensitivity AC requires jumpers in both positions 2 and 3, but ignore this for the time being.

The JP3 setting needs to duplicate the JP2 selection, ie, a jumper in position 1 for pull-up, position 2 for AC and position 3 for pull-down.

As stated though, if you don't know the settings, fit a jumper to position 4 (Autoset) of JP2 and leave the jumper off JP3.

Installation

Now for the installation, but first a word of warning: in some cars, it will be necessary to partially dismantle the dash in order to locate the power supply wirer and speed input wire to the speedo. **If you need to disassemble any of the steering wheel section, take care if an air-bag installed as this will have to be disabled.**

Generally this means disconnecting the vehicle's battery and waiting for a set period before it is safe to disassemble the column. **However, check the manual for your car and make sure you know exactly what to do to disable the airbag before proceeding. If in doubt, don't!**

In practice, the *Speedo Corrector*must be connected to either a 12V or 24V ignition-switched supply, with the 0V line going to chassis. Be sure to use automotive cable for these connections and make sure you connect to a fused supply rail (eg, for the accessories).

The signal input wire to the speedo must be cut so that the *Speedo Corrector Mk.3* can be inserted in-line with it. This wire will usually come either directly from a speed sensor or it may come from the ECU and you can generally find it in the dashboard space behind the speedometer. A wiring diagram for your vehicle will come in handy for tracking down this wire.

Depending on the vehicle, removing the dashboard panels can be a difficult undertaking and may not be something you want to do. In that case, tracking down the speed signal wire elsewhere in the vehicle is the way to go but, of course, you will need a wiring diagram. In other cases, it may

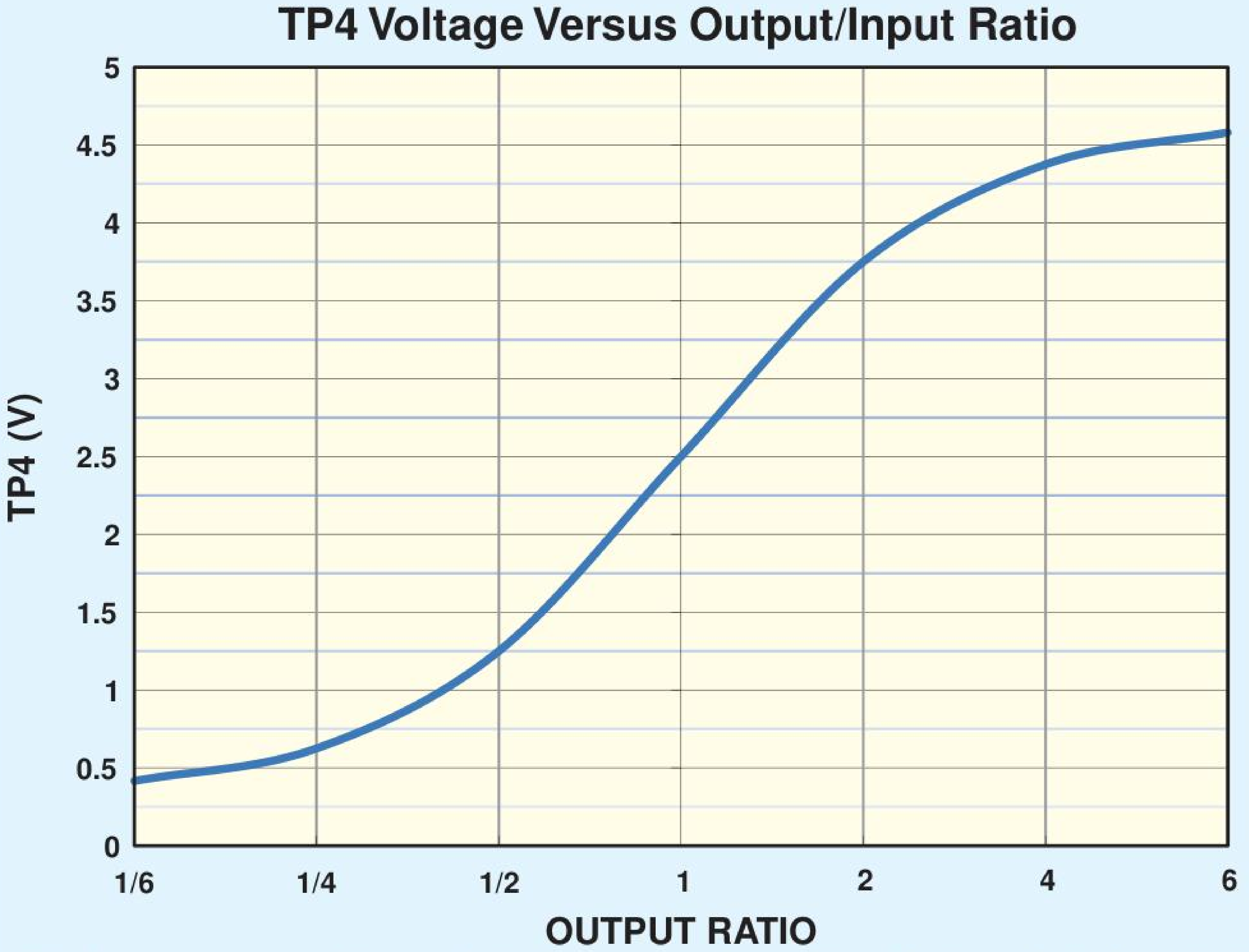


Fig.4: you can use this graph to determine the voltage that needs to be set at TP4 for a given frequency output ratio. It works in reverse too – if the *Speedo Corrector* has been adjusted using a GPS, you can determine the output ratio from the graph after first measuring the voltage on TP4.

be possible to find the dashboard disassembly instructions on the Internet, especially for older cars.

Once you've located the speed signal wire, cut it and connect the *Speedo Corrector Mk.3's* signal input to the lead coming from the speed sensor or ECU. The corrector's output is then connected to the wire running to the speedometer.

Initially, make the leads to the *Speedo Corrector Mk.3* long enough so that it can be dropped down from behind the dash and easily accessed by someone sitting in the front passenger seat. Once it's all wired up, you can jump straight to the calibration section below if you have already manually set up the jumper links.

Alternatively, for Autoset, you have to follow these simple steps:

1) Start the engine and check that LED1 lights red.
2) Drive the car for a minute or so with a passenger (note: the speedo will not be working at this stage).
3) Wait until the LED flashes green at a one-second rate. This shows that the *Speedo Corrector Mk.3* has automatically set itself to cater for the type of speedometer signal that is present and is receiving a valid signal from it.
4) Once a valid signal has been received, get the passenger to remove the Autoset jumper. Note that the power must still be on when removing the Autoset jumper in order for the settings to be stored. If this has been successful, the LED should now alternately be flashing red and green to indicate that the unit is operating normally (although the speedo will still not be working).
5) If the LED doesn't flash, check the signal wiring from the speed sensor. If the wiring is correct, try the 8.2V setting for JP1 and drive again.
6) If it is still 'no go', try manually setting the jumpers on JP2 and JP3 (they have to agree) and test each setting in turn. First, remove the Autoset jumper, then start with the Pullup jumper option (ie, position 1 for both JP2 and JP3) and drive the vehicle to see if the speedo works.

   If it doesn't, change the settings until the speedo works. Position 2 (AC) for both JP2 and JP3 can be selected next, followed by position 3 (Pulldown). The final selection to try is low-sensitivity AC, ie, install jumpers in both positions 2 and 3 of JP2 and in position 2 of JP3.
7) If you got the speedo working with the Autoset function, you now need to install a jumper at JP3. Just try each jumper setting in turn until the speedometer starts working.

   Alternatively, you can determine the set-up by making some simple voltage measurements. TP2 will be at 5V if the selection is Pulldown, while TP3 will be at 5V if the selection is Pullup. For AC, both TP2 and TP3 will be at 0V.

Tacho as well?

The *Speedo Corrector Mk.3* will also work with electronic tachos that take their feed from the ECU (ie, all cars with engine management).

The configuration procedure is the same as for use of the device as a speed interceptor, except that the 'speed sensor' becomes the tacho output signal from the ECU. This application is particularly suited to engine and gearbox swaps.

Test point TP1

OK, so what's the purpose of test point TP1? It's there so that if an Autoset sets the input for AC, TP1 can be checked to see if the associated 6.8kΩ resistor is tied to 0V for low sensitivity or left floating for high sensitivity. This may be of interest to installers so that they can check what the settings are for each vehicle. For example, if the voltage between TP1 and TPG reads 0V (with power applied), then input to the 6.8kΩ resistor is probably tied to 0V. However, if you place your finger on test point TP1 to inject noise and the voltage changes, then TP1 is floating. This means that the input to the 6.8kΩ resistor is also floating.

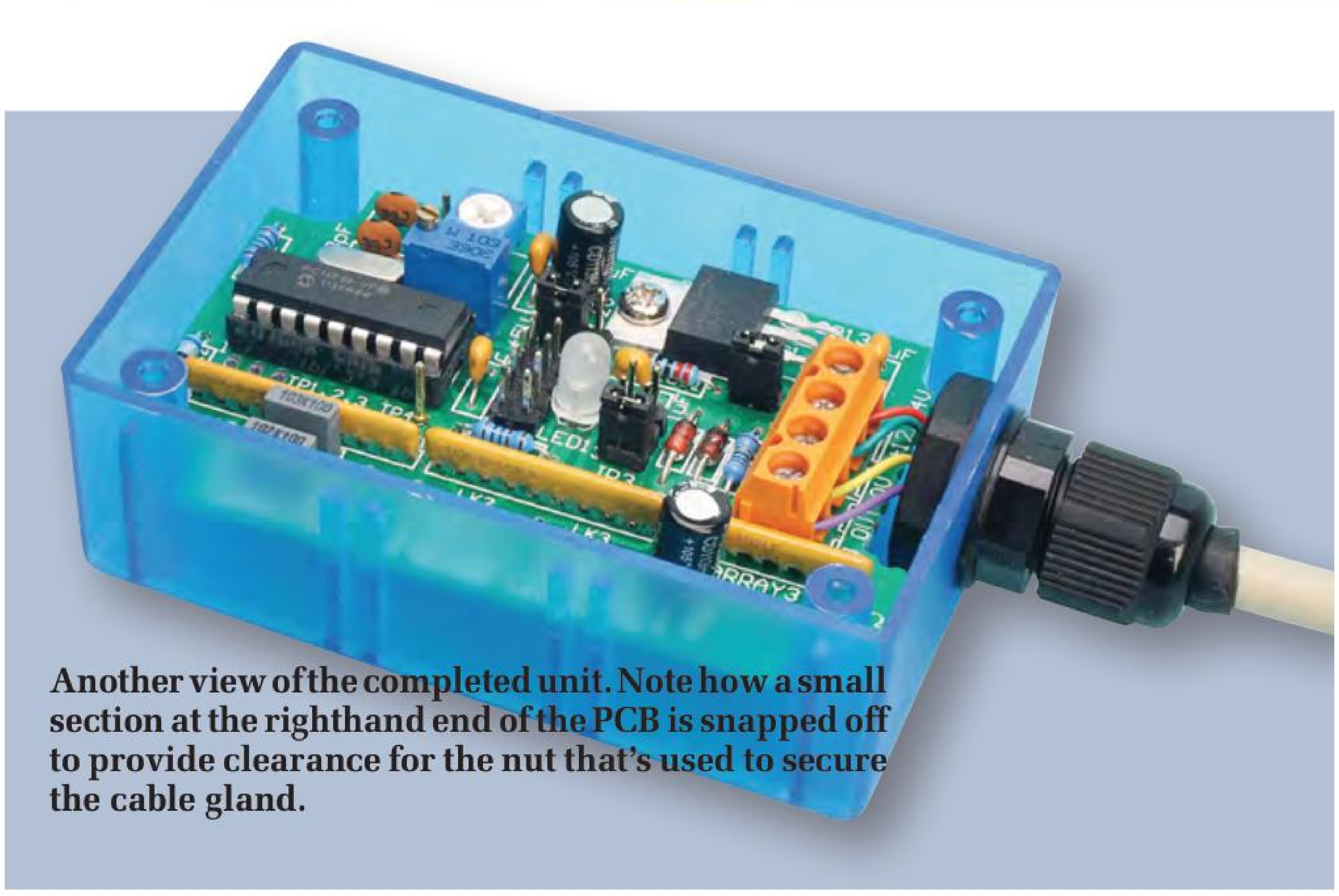
Calibration

You will need an accurate reference to correctly calibrate the speedo. This can be provided by a GPS unit or a GPS speedometer. Just make sure that you have an assistant to make the necessary adjustment as you drive! It's simply a matter of adjusting VR1 in the *Speedo Corrector Mk.3* until the speedo gives the correct reading (agrees with the GPS).

You can also use the odometer check distances that are marked on some roads to check the accuracy of the odometer.

Alternative approach

You can also adjust the *Speedo Corrector* for a certain ratio based on known wheel, differential or gearbox ratio changes. Basically, test point TP4 allows you to monitor the ratio between



Another view of the completed unit. Note how a small section at the righthand end of the PCB is snapped off to provide clearance for the nut that's used to secure the cable gland.

input and output frequency. This test point nominally sits at 2.5V when the input and output frequencies are equal, but goes above 2.5V when the output frequency is higher than the input frequency.

Conversely, TP4 goes below 2.5V when the output frequency is lower. Note that TP4's voltage is non-linear with respect to frequency changes.

The accompanying graph (Fig.4) shows the relationship between the voltage at TP4 and the output:input frequency ratio. So to set the unit for a known output ratio, simply use the graph to read off the required voltage for TP4.

Trimpot VR1 is then adjusted to bring TP4 to this value.

If a high degree of accuracy is required, measure REG1's output (Vreg) and then multiply the voltage read off the graph by Vreg/5.

You can also use Fig.4 to look up the ratio that's been set using VR1 if you have calibrated the unit against a GPS. It's just a matter of measuring the voltage at TP4 and then looking up the ratio on the graph. For best accuracy, multiply the TP4 reading by 5/Vreg before checking the ratio.

Note that the voltage reading will not provide an extremely accurate value to calculate the adjustment setting. That's because the PWM output is loaded by the indicating LED.

Final trims

If you have manually set the input selection for AC, you can experiment by also placing a low-sensitivity jumper in position 3 of LK2. This may result in smoother operation of the speedometer compared to when this jumper is left out. Select the setting that gives the best results (ie, jumper in or out).

Additionally, when there is an Autoset selection of AC (both TP2 and TP3 at 0V), the sensor signal may have required a pull-down setting in order to allow satisfactory operation at high speeds without dropping out. An inherent pull-down is provided by the 6.8kΩ resistor on the base of Q1, but this may not be sufficient to pull the signal down fast enough at high frequencies. If you experience speedometer drop-out at high speeds, try installing a jumper at position 3 for JP2 to give manual pull-down.

Another possible problem is that the speedo may some show some lag when the vehicle abruptly comes to a stop from a slow speed. When this happens, the speedo may show a reading for up to 1s after the vehicle stops.

Speedo lag could also be evident when moving off from a standstill. In this case, the speedo initially shows 0km/h before then suddenly jumping to the correct speed reading.

This problem can be overcome by adjusting response trimpot VR2. At its full anticlockwise position, the response lag is 1s. As the trimpot is adjusted clockwise, the response becomes faster at 0.5s and then 0.25s at mid-setting. Further rotation provides 0.125s and then 62.5ms at VR2's full clockwise position.

The optimal setting is when the adjustment provides the shortest lag while still reliably operating the speedo at slow speeds.

Once the *Speedo Corrector* is working properly, the lid can be attached and the unit tucked up behind the dash out of sight.

PoLabs

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By ROSS TESTER

LED PARTY STROBE

Here's a brilliantly simple and cheap design for an LED Party Strobe. We've used a standard 230VAC 30W LED floodlight which can be purchased quite cheaply online.

There is a common misconception that high power LEDs cannot be strobed – turned on and off quickly – for a very similar reason that an incandescent bulb cannot be strobed.

Incandescent lamps have a high thermal inertia – their lamp filaments don't have a chance to cool down enough after each 'flash'.

So even though the current through a filament may be switched on and off rapidly, the filament temperature responds much more slowly; very slowly, in fact.

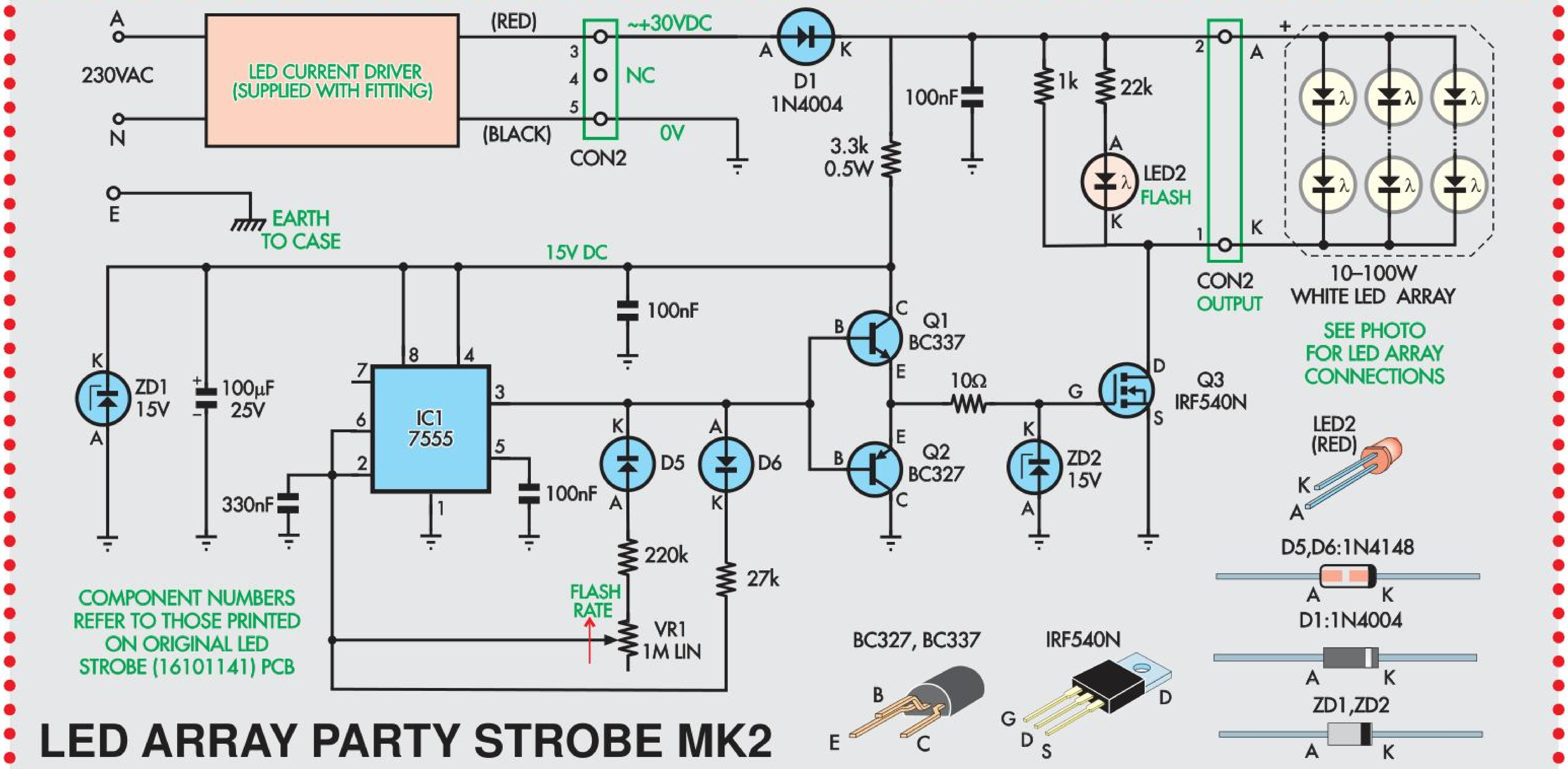
LEDs don't have the inertia of filaments. White LEDs are typically based on blue LEDs with an accompanying phosphor that produces the white light. And that is where the misconception arises because phosphors in fluorescent tubes do have inertia – certainly quite a lot of it. So when you switch a fluorescent light off, it takes a significant amount of time before the phosphor stops emitting light.

However, the phosphor in white LEDs does not emit light by phosphorescence; it works by a process called scintillation.

That means that there is no light persistence after each flash. In fact, our tests demonstrate that these very bright LED floodlights can be flashed very rapidly indeed, up to 10kHz or more is easily done.

However, for a party strobe-light the flashing is not rapid at all, up to only about 18 flashes per second.

This *LED Party Strobe* is based on a 230VAC LED floodlight, sold in large numbers via the internet with ratings of 10W, 20W, 30W, 50W or 100W. The mains-powered LED driver is supplied already fitted and wired inside the case. All are quite similar in


A
230VAC
N
E
LED CURRENT DRIVER (SUPPLIED WITH FITTING)
(RED)
(BLACK)
~+30VDC
NC
0V
CON2
3
4
5
D1 1N4004
100nF
3.3k 0.5W
1k
22k
LED2 FLASH
EARTH TO CASE
15V DC
CON2 OUTPUT
10–100W WHITE LED ARRAY
SEE PHOTO FOR LED ARRAY CONNECTIONS
ZD1 15V
100µF 25V
IC1 7555
330nF
100nF
D5
D6
220k
27k
FLASH RATE
VR1 1M LIN
Q1 BC337
Q2 BC327
10Ω
Q3 IRF540N
ZD2 15V
LED2 (RED)
D5,D6:1N4148
D1:1N4004
ZD1,ZD2
BC327, BC337
IRF540N
COMPONENT NUMBERS REFER TO THOSE PRINTED ON ORIGINAL LED STROBE (16101141) PCB

LED ARRAY PARTY STROBE MK2

Fig.1: the circuit is a simplified version of an earlier design – mainly because the mains power supply is already supplied fitted to the floodlight.

presentation with their overall size increasing according to their rating.

The one featured in this article is rated at 30W, but you could use any rating from 10W to 100W. However, we think 30W is probably enough.

230VAC LED current driver

Not only is the construction of all these LED floodlights similar, their internal circuitry is much the same, comprising a switchmode current driver module rated for inputs of between 160 to 265VAC, or thereabouts. The current-driver module is housed in a rectangular metal housing with plastic end pieces and it is typically held in place in the rear casing of the LED floodlight with silicone sealant.

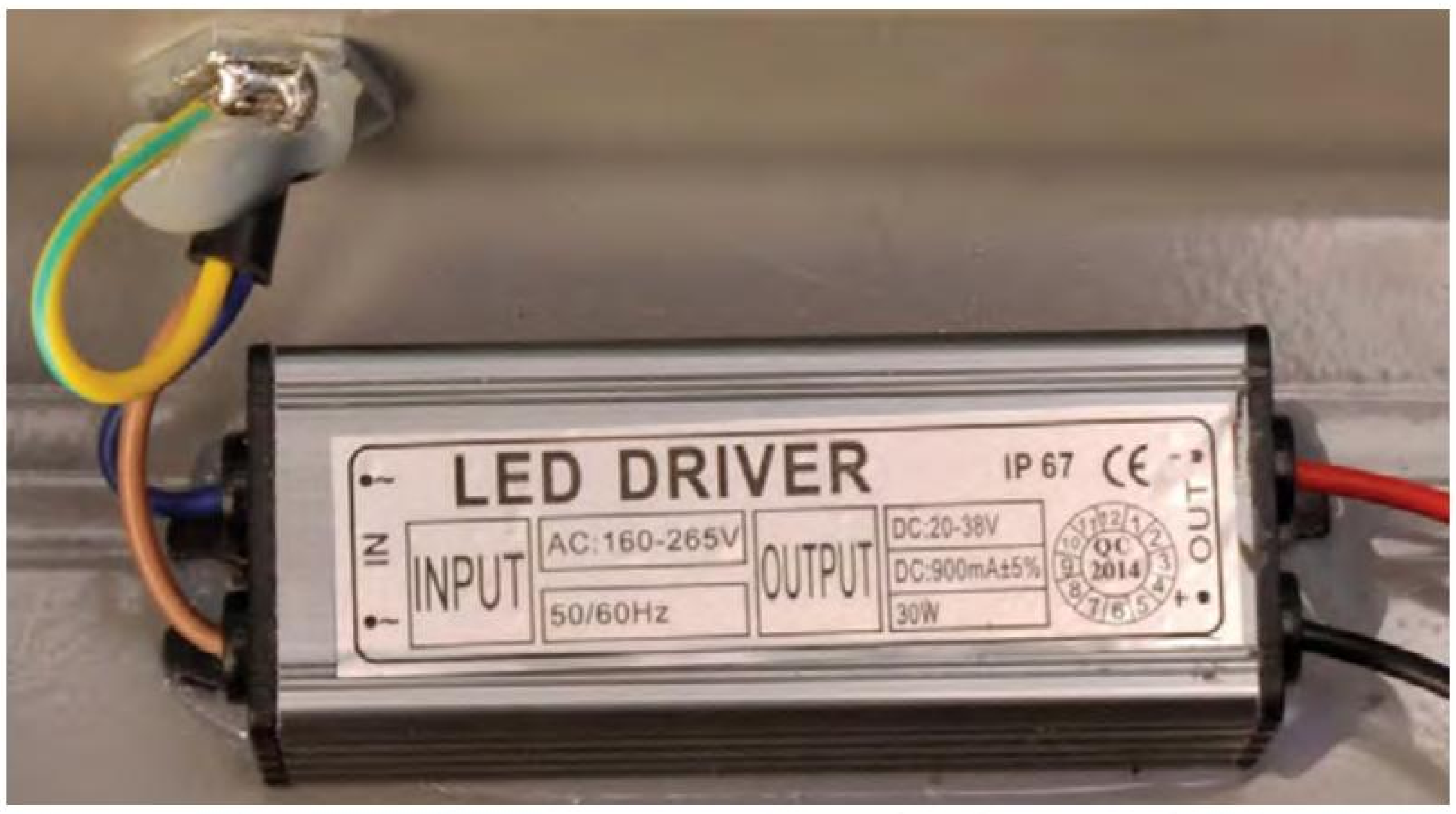
The output voltage of these current-driver modules is typically around 30 -36V DC, and in the example we are using here the current rating is 900mA.

And how are we flashing it? We are using the switching module shown in the diagram of Fig.1.

The LED driver output of about 30V DC is fed via diode D1 directly to the anodes of the 10W to 100W white LED array and also via a 3.3kΩ 0.5W resistor to a 15V zener diode, ZD1. This provides a 15V DC supply rail to a 7555 timer (IC1) and transistors Q1 and Q2.

IC1 is connected so that it repeatedly charges and discharges the 330nF capacitor at pins 2 and 6 via diodes D5 and D6 from its pin 3 output.

The two diodes provide different charge and discharge times because of the different series resistances. For example, the charging path is via D6 and the 27kΩ resistor, while the


LED DRIVER
IP 67
IN
INPUT
AC:160-265V
50/60Hz
OUTPUT
DC:20-38V
DC:900mA±5%
30W
QC 2014
OUT

Above is the LED driver mounted inside the case (held in place by silicone sealant [which is quite OK]). The mains input lead is secured with a captive gland but the earth connection is not up to par. We will refit this to the proper standard. At right is the rear view. As mentioned in the text, we should have fitted the pot much further forward so it didn't foul the mounting bracket. Speaking of which, we had previously cut this to suit our location – it's normally a single 'U' shape.

Commercial strobes

We are aware that you can purchase ready-built LED strobes online, for not much more than the cost of an LED floodlight. But we're not convinced that the commercial models are as good as ours!

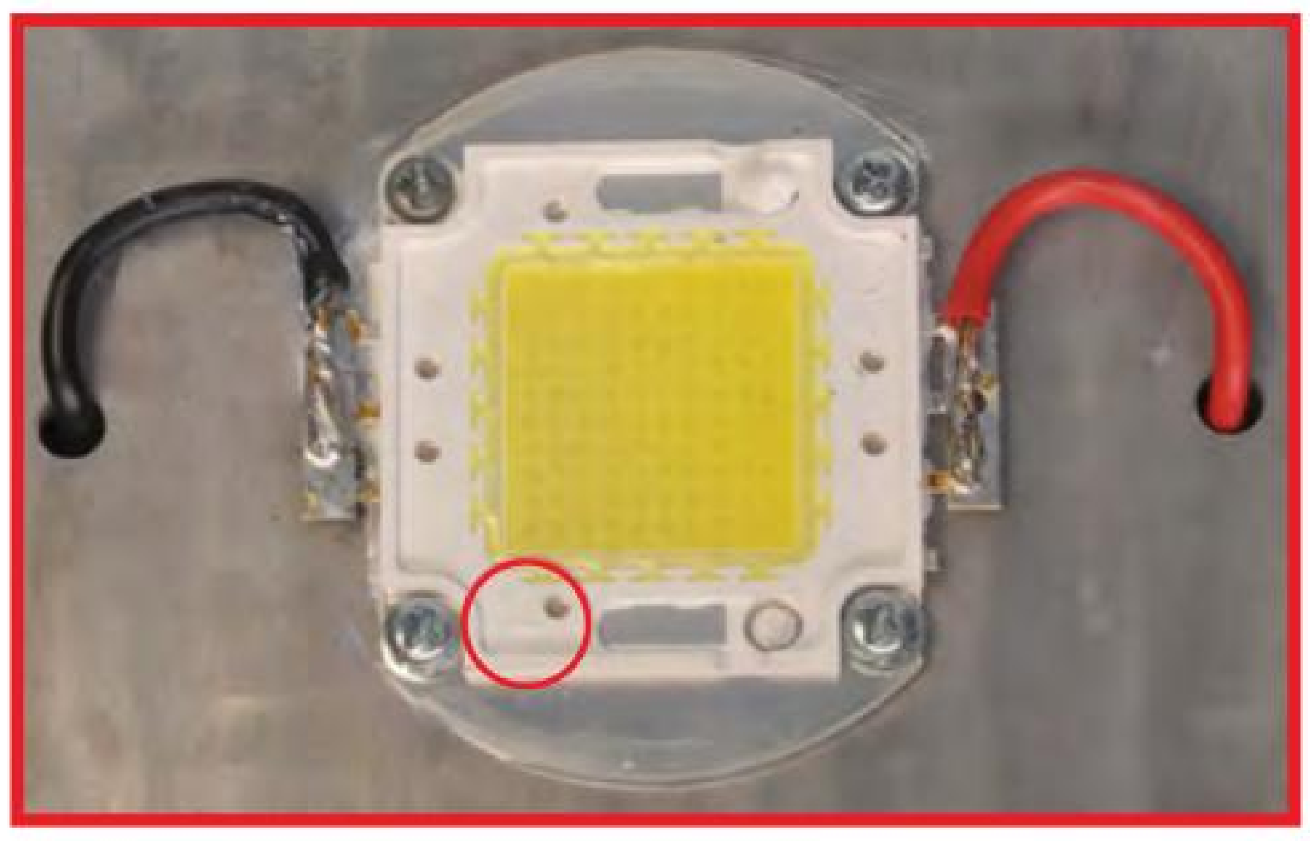
You can also buy a variety of LED arrays, either fitted to a floodlight housing (as ours was here) or loose. 'Naked' LED arrays are commonly available in 10W, 20W, 50W, 70W and 100W ratings at quite attractive prices (100W LED arrays, for example, are less than £10.00 each!).

Incidentally, Xenon-tube strobes are still available. But we've seen some pretty extravagant claims of Xenon strobes power – for example, 1500W in one case! Now, when you consider that the majority of Xenon tubes we used to use in DIY strobes were usually rated at 5W (actually 5 joules, or 5 watt-seconds) 1500W or even 1000W would seem to be a *bit* over the top. It's not dissimilar to a 5W RMS audio amplifier being advertised as 1000W PIMPO. In those immortal words from 'The Castle' . . . *they're dreamin!*

discharge path is via D5, the 220kΩ resistor and the 1MΩ potentiometer, which is wired as a variable resistor (rheostat).

The result is a fixed flash duration of 8ms (milliseconds) and a flash rate which can be varied from about three flashes per second (fps) up to about 15 fps. The flash rate is a compromise between apparent brightness and the 'freeze motion' effect which is the whole point of a strobe.

The variable pulse train from pin 3 of IC1 is fed to the complementary transistors Q1 and Q2 and these buffer



If you unsolder the LED array, or want to replace it, identifying the anode and cathode can be rather difficult. Look for a '+' sign moulded into the plastic (indicated by the red circle above). Contrarily, this is closest to the – terminal or cathode (see red and black wires). *Never* operate the LED array without it being secured to a heatsink.

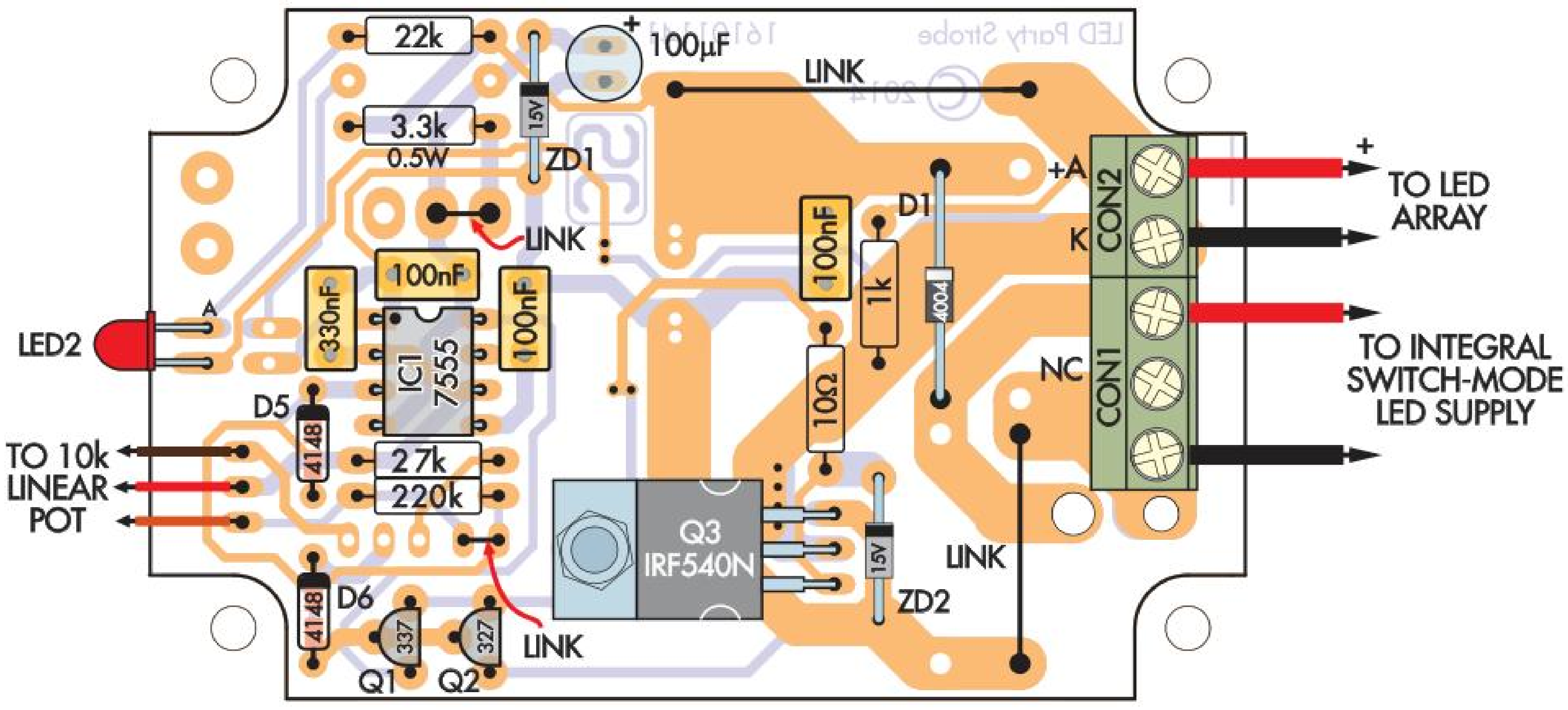


Fig.2, the PCB component overlay, which matches the same-size photo at right. This is the same PCB as used in an earlier (see Version box) *LED Party Strobe* but the circuit is simpler, as evidenced by the number of empty holes. Note also the four links required. Only the red and orange wires to the pot are actually required, but we had a length of 3-wire cut from a ribbon cable so used it!

the output to provide cleaner switching of the following N-channel MOSFET Q3, an IRF540N and this is connected to the cathodes of the LED array to provide the rapid switching.

Since the average current is only around 1A maximum for a 100W LED array, no heatsink is required for the MOSFET.

A 1kΩ resistor is connected across the LED array to damp high frequency artefacts from the LED current driver. At the same time, a red LED fed by a 22kΩ resistor provides a visible indication that the circuit is working if the LED array is not actually connected or cannot be seen.

Obviously, this LED will not be visible once the switching PCB is housed inside the casing of the LED floodlight.

Note that the LED driver does not appear to be 'troubled' by having its current output interrupted by this switching process. In fact, its output voltage will tend to rise to about 40V at low flash rates, but then it simply shuts off intermittently to limit the output voltage to a safe level.

Construction

Like the earlier party strobe, this one is constructed inside an LED floodlight fitting. Unlike the earlier model, though, it is wholly self-contained because the floodlight is designed to operate off AC power (160-265V) through its tiny switch-mode supply module already fitted inside.

Believe it or not, mains-powered LED floodlights are not significantly more expensive than their 12V counterparts. We obtained ours online for about £20 – prices do vary significantly so shop around!

The PCB is also mounted inside the fitting – but where the supply module is mounted inside the 'lid', we secured the new PCB inside the body of the fitting, so that when the two halves are brought together, the new PCB clears the supply module. There is not a huge amount of space to spare – but there is enough.

We're getting a bit ahead of ourselves, but we used double-sided thick foam pads to secure the PCB to the case. These have several advantages, not the least of which is that they don't require any drilling and also act as insulators between the bottom side of the PCB and the metal case.

Double-sided foam pads are commonly available at stationery stores, office suppliers and newsagents.

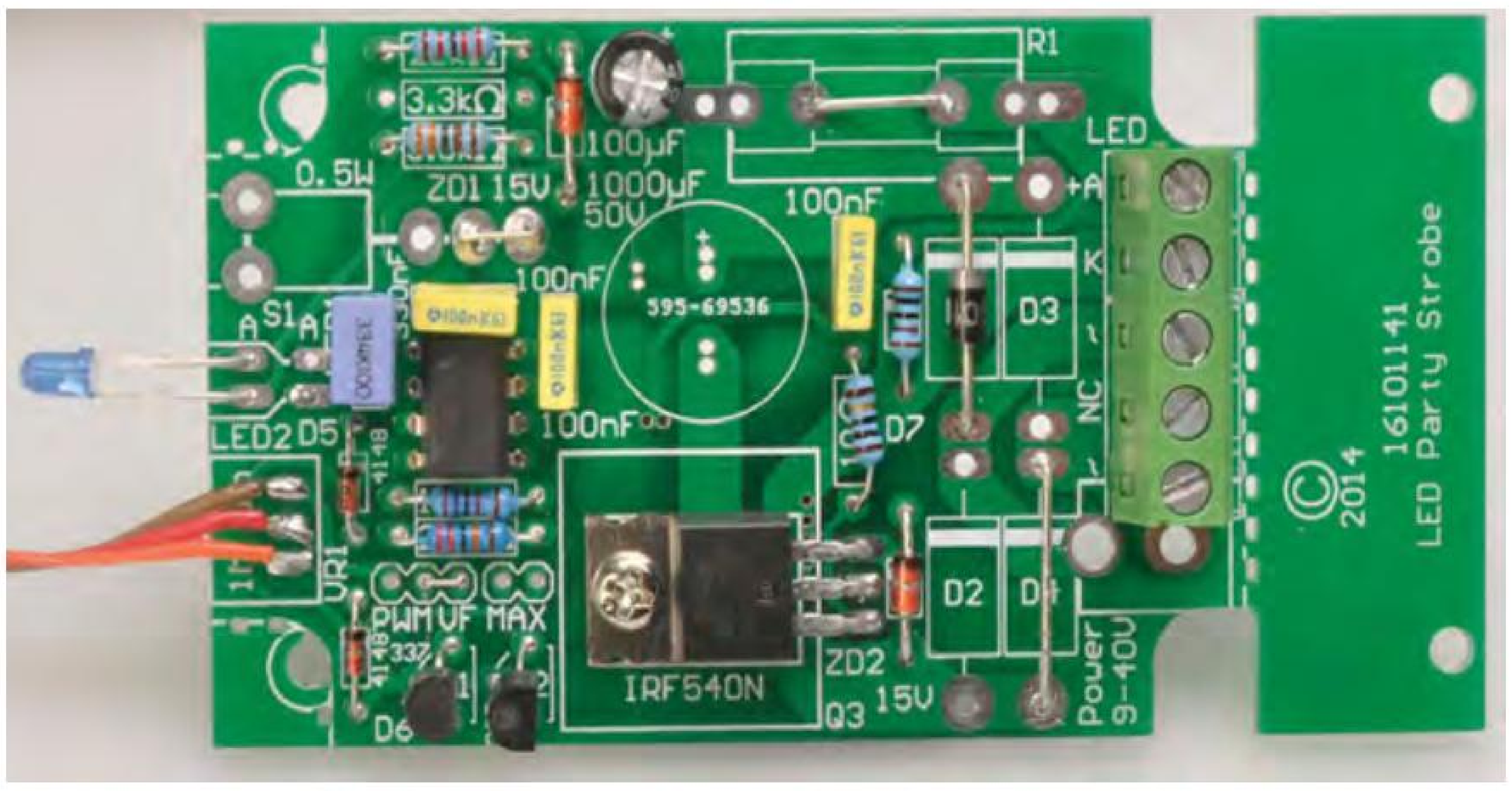
Assembling the PCB

This is quite straightforward using a PCB designed for an earlier strobe (not published in *EPE)*, part number 16101141 available from the *EPE PCB Service*.

Constructors will note that using this PCB several component positions are left unfilled and some components are slightly different to those indicated on the silk screen. We have retained the component identification numbers

Which version is this?

This *LED Party Strobe* was originally published by *SIlicon Chip* magazine. In fact, it was their second version. The first did not appear in *EPE*, so where you see references to 'Mk II' then remember that refers to this project. The PCB is the same as the Mk I version, but with component changes, as detailed in the text.



Due to its earlier multi-use format, the PCB had an end which could be cut off – shown above at the right end (but cut off in the overlay at left). It's up to you. As mentioned in the text, the LED is redundant once the case is closed – but it saves your eyes from the *REALLY BRIGHT* LED array while testing!

from the silk-screen PCB overlay on the original PCB to avoid confusion; there will obviously be 'gaps' in the component numbering (eg, there is a D1, D5 and D6 but no D2, D3 or D4).

Simply follow the Parts List opposite, noting which components are left out and which are replaced by a wire link.

Start with the lowest-profile components first, ie the resistors and small capacitors.

Follow these with the diodes and Zener diodes, taking care to neither mix them up nor get them around the wrong way.

Next are the LED and transistors (again, the BC327 and BC337 appear identical so watch their position).

Strictly speaking, the 'flash' LED (LED 2; there is no LED 1) is not really required because when the unit is complete, it will be hidden inside the case.

However, we left it in situ because, for the sake of a few pence, it meant we could confirm proper operation without having to connect the blindingly bright LED array until we had to!

Next, bend the leads of the MOSFET down 90° in the appropriate place so it can mount flat on the PCB with its screw hole aligned with the hole in the PCB.

Many people find it easiest to temporarily screw the MOSFET to the PCB, grip the leads in the right place with a pair of fine pliers, remove the screw while still holding the leads with pliers and then bend them down along the edge of the pliers.

Now, snap together the two-way and three-way terminal blocks and solder them in position as a five-way, with the access facing towards the outer edge of the PCB.

Only four terminals are used; position number four is not connected.

The last component to mount is the 7555 timer IC – make sure its notch goes in the same orientation as the graphic on the screen overlay. Whether you use an IC socket is entirely up to you (but if you do, make sure its orientation is the same).

Mounting the speed pot

Unlike the earlier strobe, the speed pot is mounted external to the board via a short length of ribbon cable. While only two wires are required (shown in red and orange on the overlay diagram) we wired all three terminals.

Make the ribbon cable (and indeed the connections to the LED array and the switch-mode supply long enough to be able to open the two halves of the case to work on. We found that we needed to lengthen some of the cables with short lengths of the same colour hookup wire, with the soldered joints covered by heatshrink insulation.

With 20/20 hindsight, we wouldn't have mounted the pot in the middle of

Parts list – LED Party Strobe

1 double-sided PCB, available from the *EPE PCB Service*, coded 16101141, 95 × 49.5mm (First used January 2014)
1 10 to 100W LED floodlight, mains operated (see text)
1 2-way terminal block (CON1)#
1 3-way terminal block (CON2)# (combine to make 1 × 5-way)
1 short length tinned copper wire
1 knob to suit VR1
1 3-pin mains plug
1 M3 6mm machine screw and nut
4 double-sided foam adhesive pads
1 100mm length 3-way (or 2-way) rainbow cable
Short lengths heatshrink tube
Short lengths red and black hookup wire

Semiconductors
1 7555 CMOS timer (IC1)
1 BC337 NPN transistor (Q1)
1 BC327 PNP transistor (Q2)
1 IRF540N MOSFET (Q3)
1 3mm red LED (LED2)
1 1N4004 1A diode (D1)
2 1N4148 signal diodes (D5,D6)
2 15V 1W Zener diodes (ZD1,ZD2)

Capacitors
1 100µF 25V electrolytic
1 330nF MKT *(code 334, 330n or 0.33µF)*
3 100nF MKT *(code 104, 100n or 0.1µF)*

Resistors (0.25W, 1% unless otherwise stated)
1 220kΩ *(code red red yellow brown or red red black orange brown)*
1 27kΩ *(code red purple orange brown or red purple black red brown)*
1 22kΩ *(code red red orange brown or red red black red brown)*
2 3.3kΩ 0.5W *(code orange orange red brown or orange orange black brown brown)*
1 1kΩ *(code brown black red brown or brown black black brown brown)*
1 10Ω *(code brown black black brown or brown black black gold brown)*
1 1MΩ linear 9mm potentiometer (VR1)

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the case because it restricts the travel of the mounting bracket.

Fortunately, this didn't matter too much in our case, but if you need to be able to swing that bracket over a wide arc to aim the strobe where you want it, mount the pot as far up the case as you can.

Aaagh – no power plug!

Probably because the floodlight is sold to all corners of the earth (it does have a 160-265V supply), there is no power plug fitted.

But perhaps worse, the mains lead is only about 200mm long, so you'll either need to fit a mains plug and use it with an extension cord, or fit a mains junction box to the short cable.

Whatever you choose, ensure that your mains wiring is safe and triple checked before use.

Testing it

After checking your component placement and soldering, connect the assembled PCB to the switch-mode supply module (watch the polarity!) without yet connecting the LED array.

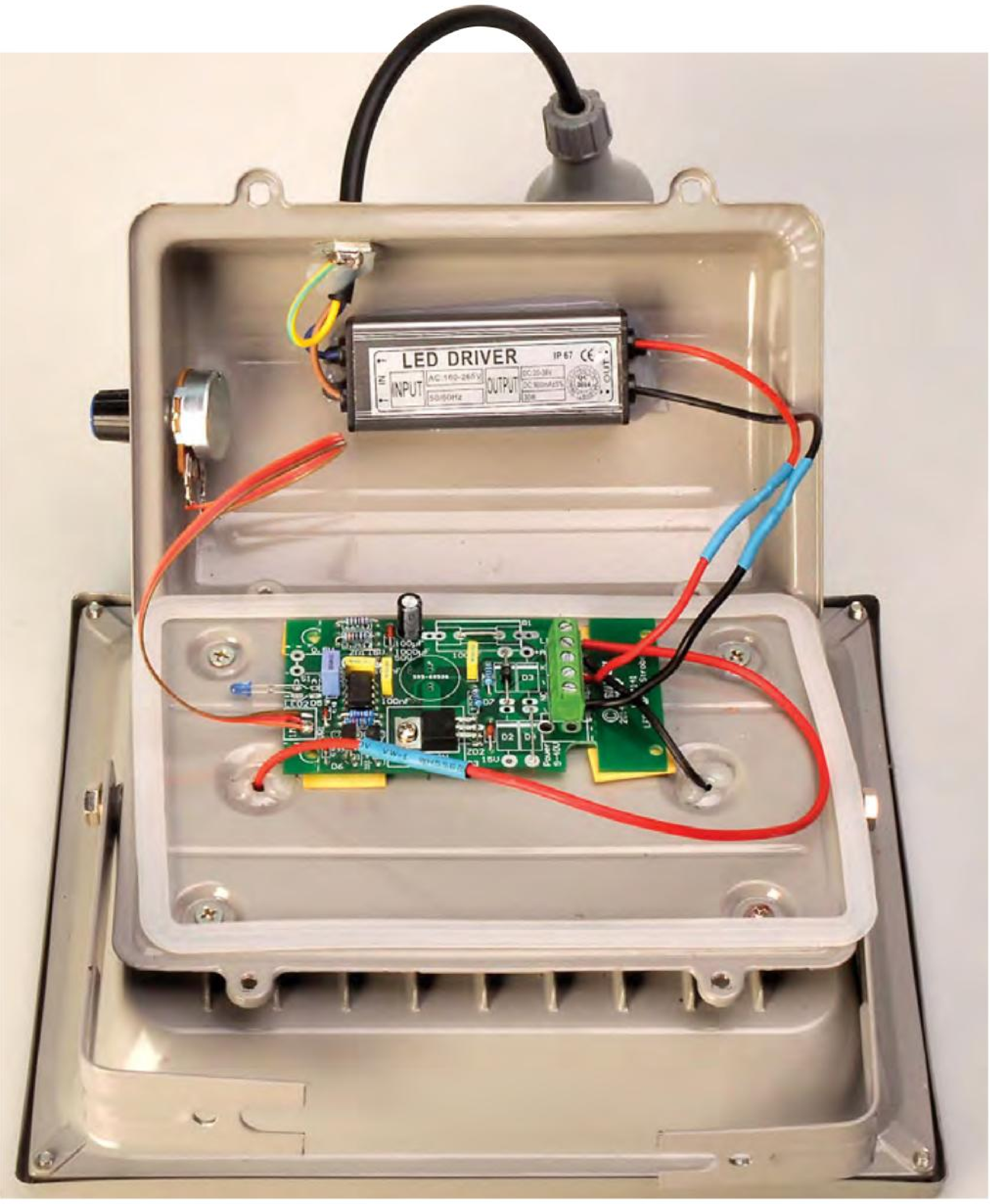
Connect the mains plug and switch power on. You should find that the 'flash' LED does just that – flash – with timing (ie, flash rate) adjustable via the potentiometer.

If it doesn't, you obviously have a component error or bad solder joint. Check the voltage across the power input terminals (3 and 5; remember 4 has no connection) where you should read somewhere around 30V DC.

If this is OK, check the voltage across pins 1 and 8 of the IC – that should be very close to 15VDC.

If this is OK, the only possibility is (again) a wrongly-placed component or a bad solder joint. Make sure you haven't mixed up the Zener diodes and the signal diodes (D5/D6), or that you haven't swapped the two transistors (Q1 and Q2).

If you find that the LED flash rate is highest when the pot is at minimum, simply reverse the connections to the pot (the ones shown in red and orange).



Here's the almost-completed *LED Party Strobe*, immediately before we fixed that dodgy earth termination and then joined the two halves of the case. You can see the four adhesive foam pads we used to secure the new PCB to the case, along with the lengths of heatshrink cable over wire joins to prevent shorts. Make sure you have the neoprene washer in situ before screwing together AND that none of your internal wiring is poking out! Incidentally, we had to fit a three-pin mains plug and the floodlight is supplied with only a very short mains cable.

Connect the LED array

If everything checks out, unplug it and wait for the Flash LED to stop flashing. Then connect the wires to the LED array (watch the polarity!).

Turn the reflector away from your eyes and briefly plug the power in again. You should be rewarded with some very bright flashes – again, adjustable via the flash rate pot.

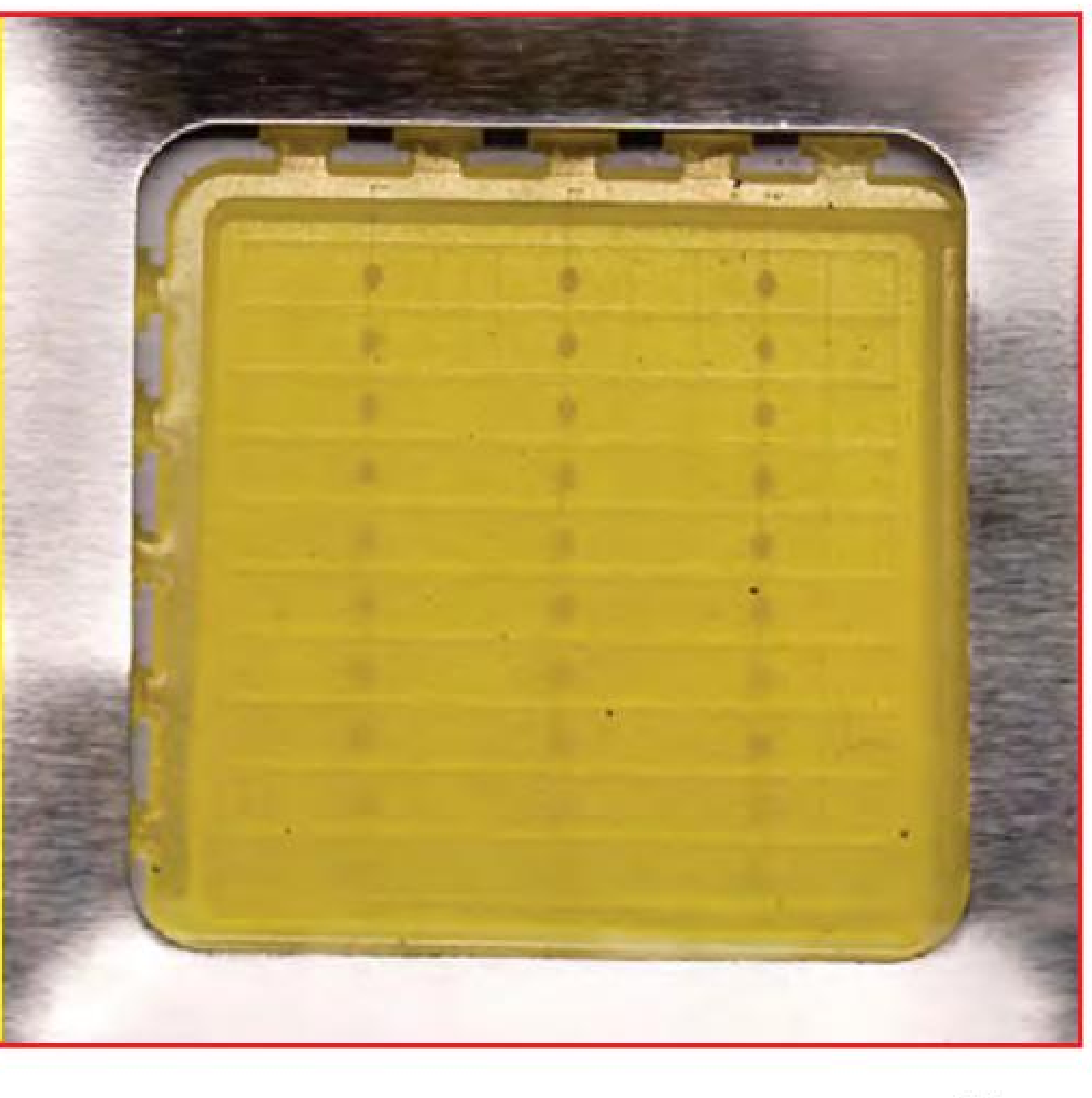
Screw the case together, ensuring that the gasket is in place and that none of the internal wires have managed to spill outside the case. And that's it: your *LED Party Strobe* is now complete. Finally, throw a party!

WATTS THE LED ARRAY POWER?

There is no marking on the LED arrays to tell you what the power is. But this one is a 30W array; the one overleaf is a 100W type. How do we know?

Simple: count the number of vertical rows. Each row accounts for 10W; here there are 3 rows so it's a '30 watter'. The one overleaf has 10 rows, so it is a 100W type.

As mentioned earlier, don't be tempted to operate these without a heatsink (they don't need insulation) and if you stare straight into them, well, your mother told you...

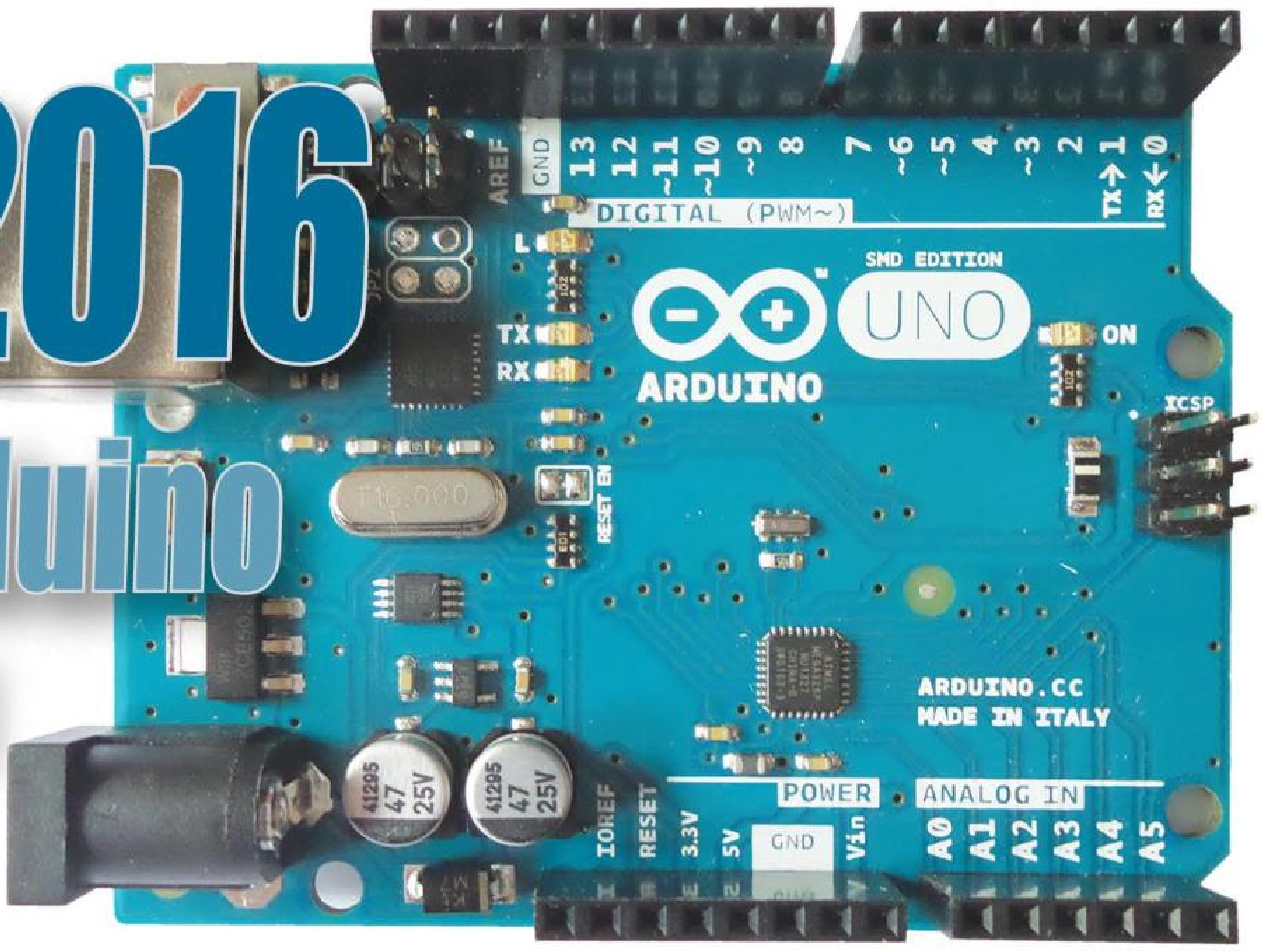


Teach-In 2016

Exploring the Arduino

Part 8: IR remote control

by Mike and Richard Tooley



Welcome to *Teach-In 2016 – Exploring the Arduino*. This exciting new series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Arduino microcontroller as well as coding enthusiasts who want to explore hardware and interfacing. So, whether you are considering what to do with your Arduino, or maybe have an idea for a project but don't know how to turn it into reality, our new *Teach-In 2016* series will provide you with a one-stop source of ideas and practical information.

In last month's *Teach-In 2016, Arduino World* we looked at the Arduino Uno's diminutive cousin, the Arduino Nano. This tiny microcontroller provides you with a highly cost-effective alternative to the Uno that's small enough to be tucked away into an extremely small space. *Arduino Workshop* introduced you to passive infra-red (PIR) motion sensors, and our programming feature, *Coding Quickstart*, introduced tone generation. Finally, our *Get Real* project described the design and construction of an Arduino Nano-based PIR motion alarm.

This month

In this month's *Teach-In 2016 Arduino World* we will be continuing with the infra-red theme by looking at how IR remote control can be added to your Arduino Uno and Nano projects. *Arduino Workshop* will introduce you to infra-red transmitters and receivers, and *Coding Quickstart* looks at the infra-red remote library. Finally, our *Get Real* project describes the design and construction of an Arduino multi-channel infra-red remote controller that will allow you to control lighting, heating and a host of other gadgets from your armchair.

Arduino World: IR remote control and the Arduino

Last month, we looked at an application using infra-red (IR) – a simple Arduino-based intruder alarm. This month, we look at a different use for IR technology in a range of remote control applications. IR is widely used as a means of remotely controlling audiovisual equipment, such as TV and DVD players. There's no need to get up out of your armchair to adjust the volume or change channels. The technology is tried and tested and has been widely available in the domestic market for more than 20 years. There are several different implementations of the technology, but they are closely related and use the same basic components: IR transmitters and receivers.

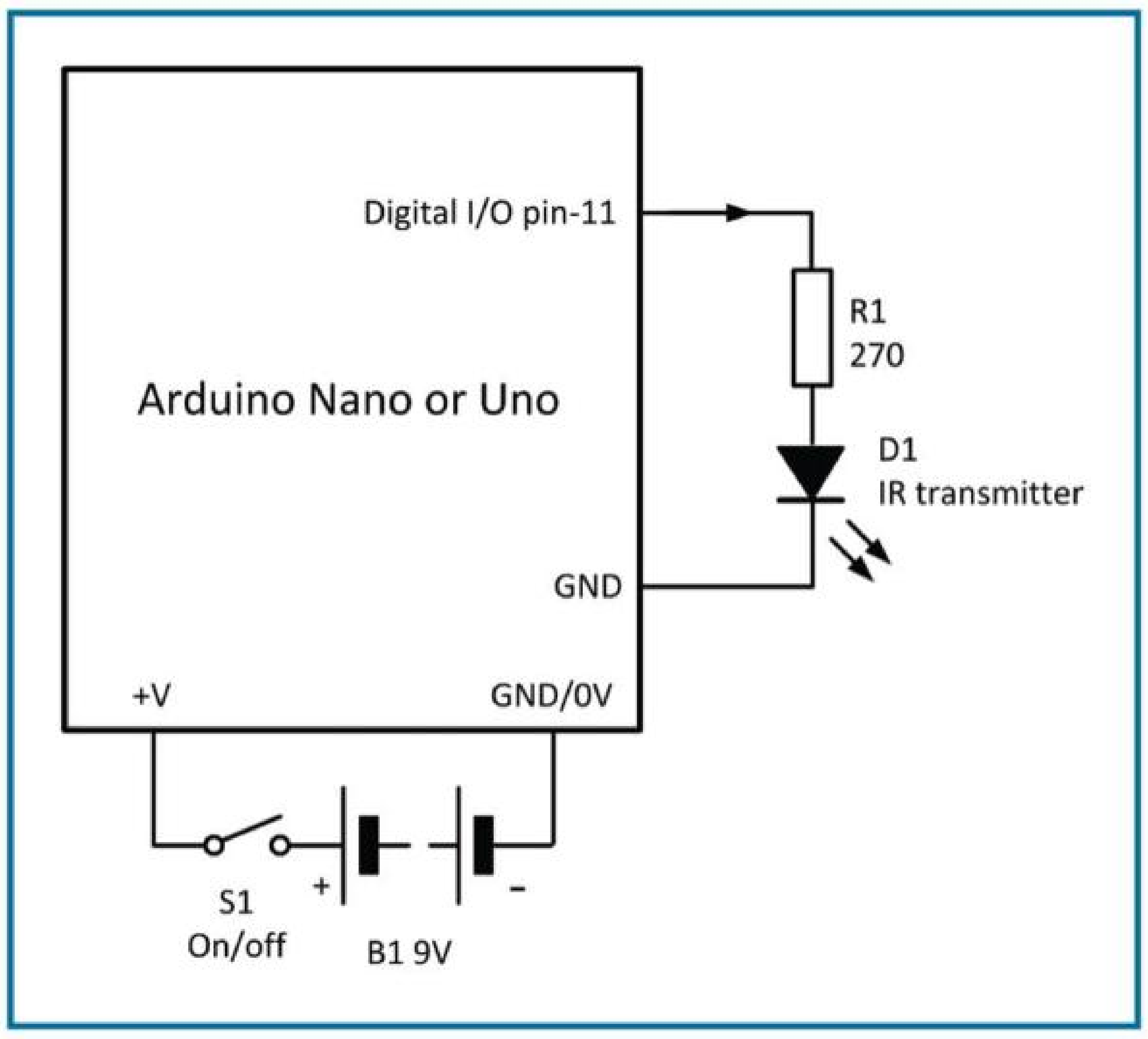


Fig.8.1. A simple IR transmitter based on a standard IR emitter and an Arduino

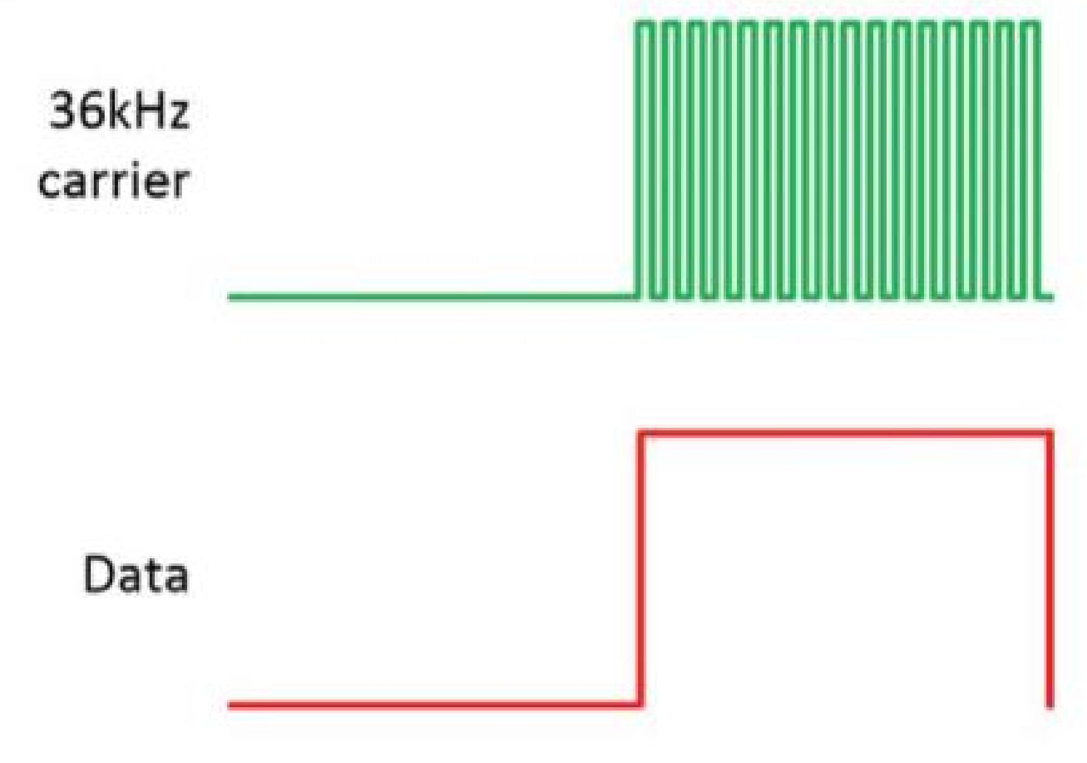
Infra-red light is electromagnetic radiation similar to light but invisible to the human eye. The normal wavelength range for semiconductor light sources is 700nm to 950nm, whereas visible light occupies the range 400nm to 700nm.

IR emitters

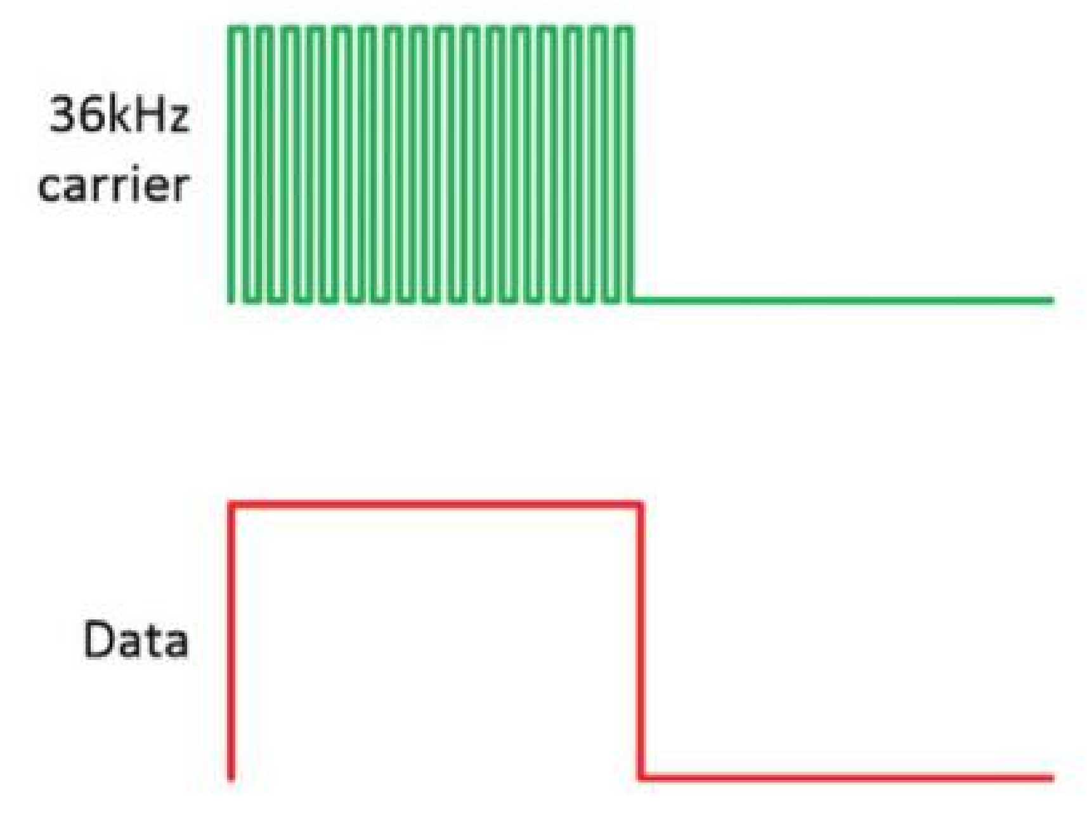
To generate a beam of IR light we can make use of a low-cost semiconductor device similar to a standard LED, but with peak output around 875 to 950nm at forward voltages of around 1.5V. In order to send data via an IR link the signal to the IR emitter needs to be modulated with data. This is normally achieved by pulsing the IR emitter on and off at a fixed rate for intervals of time corresponding to the stream of data that is being sent. The rate that is chosen is often 36kHz, 37.9kHz, 38kHz or 40kHz. A simple IR transmitter based on an Arduino Uno and a standard IR emitter is shown in Fig.8.1.

Bi-phase encoding

The method of data encoding uses a bi-phase (or 'Manchester encoding') technique. In this system a transition occurs in the middle of each bit period with a low-to-high transition representing one logic state, while a high-to-low transition indicates the opposite logic state. Synchronisation is facilitated by the transition that occurs in the middle of every time frame, providing a means of self-clocking the received data stream. Since this might be new to readers it is worth explaining in the context of an IR-based remote control in which a single bit is typically transmitted within a time frame of 888µs. A logic 0 is represented by no light output for the first half of the time frame



(a) Logic 0 encoding



(b) Logic 1 encoding

Fig.8.2. Sending data via an IR emitter

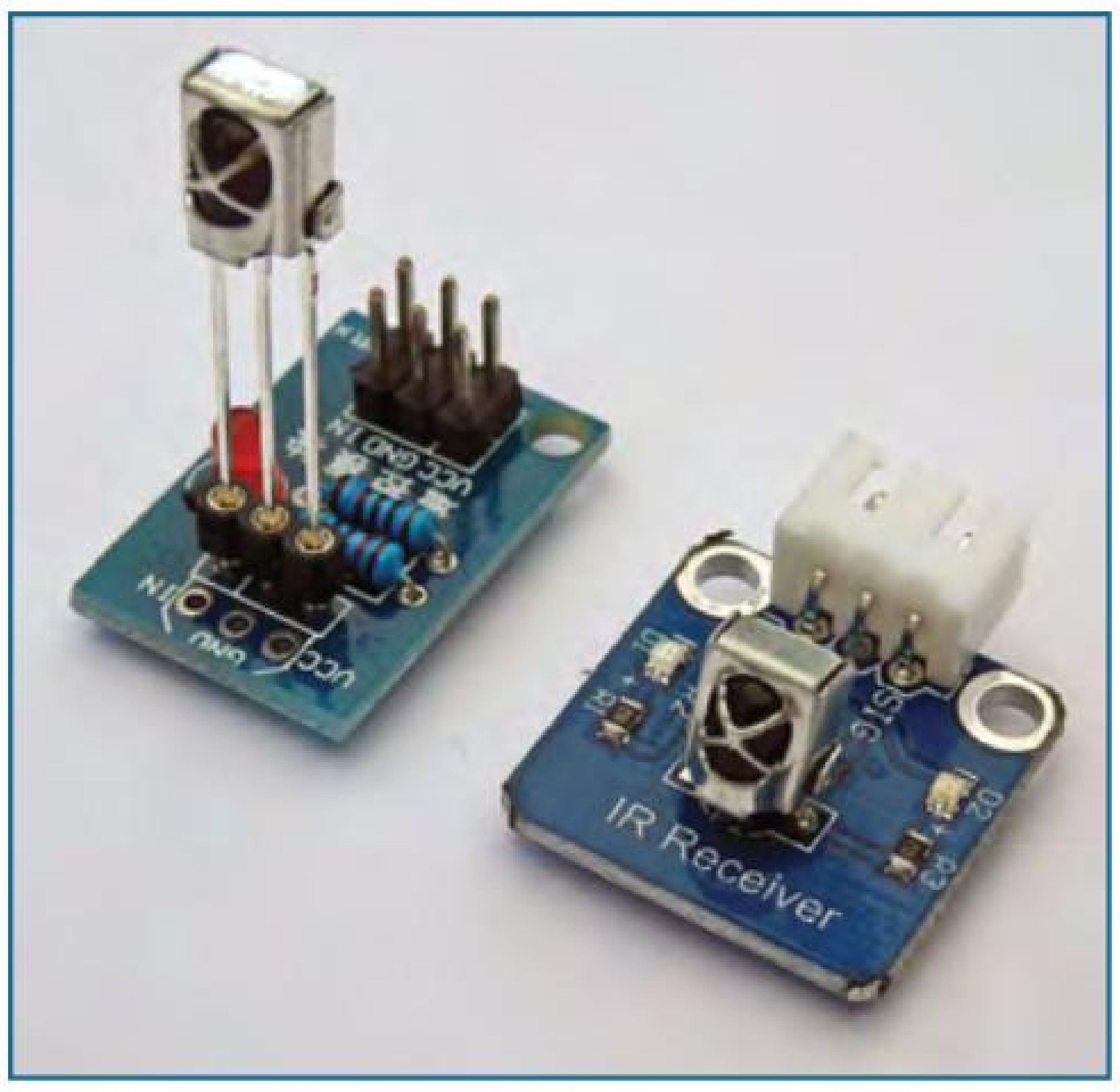


Fig.8.3. Typical IR receiver interface boards – the IR receiver chip has three pins: Vcc, GND and signal output.

(444µs) followed by a burst of IR light during the second half of the time frame (444µs). Conversely, a logic 1 would be represented by a burst of light for the first half of the time frame (444µs) followed by no light output for the second half of the time frame (444µs). We've illustrated this bi-phase encoding in Fig.8.2.

IR receivers

An IR receiver (see Fig.8.3) is simply an integrated circuit that incorporates an IR sensor (usually a PIN diode) along with an amplifier and a means of decoding IR signals so that the output appears as a logic-compatible data stream. A complete IR receiver based on an Arduino Uno is shown in Fig.8.5.

The AX-1838HS IR receiver chip

The AX-1838HS chip used in the IR receiver shown in Fig.8.3 is found in a wide range of IR remote-control applications. The chip incorporates an IR filter to offer improved ambient light rejection. The IR sensor is a PIN diode and this is followed by a preamplifier and second amplifier stage, followed by a limiter which produces a logic-compatible signal at the PCM carrier frequency (typically 36kHz). This signal is then fed via an internal bandpass filter, demodulator and integrator. The baseband output of the integrator is then fed to a comparator and an open-collector output stage that provides a logic-compatible output.

The AX-1838HS chip is ideal for use with the Arduino. It can operate from either a 3V or 5V supply with an output that is compatible with conventional TTL and CMOS logic. The spectral response of an AX-1838HS IR receiver is shown in Fig.8.6, while its angular response is shown in Fig.8.7. The pin connections for the device are shown in Fig.8.8.

Philips RC-6 protocol

Various protocols are used for sending data via IR. One of the most popular is the RC-6 protocol developed by Philips, which is used by various devices including Sky satellite receivers. The RC-6 protocol supports several different modes of operation. RC-6 signals use a 36kHz IR carrier. As described previously, data bits are represented by transitions between the two logic states. A leader pulse precedes the block of data; a start bit, three mode bits, and a trailer bit, as shown in Figs.8.9 and 8.10.

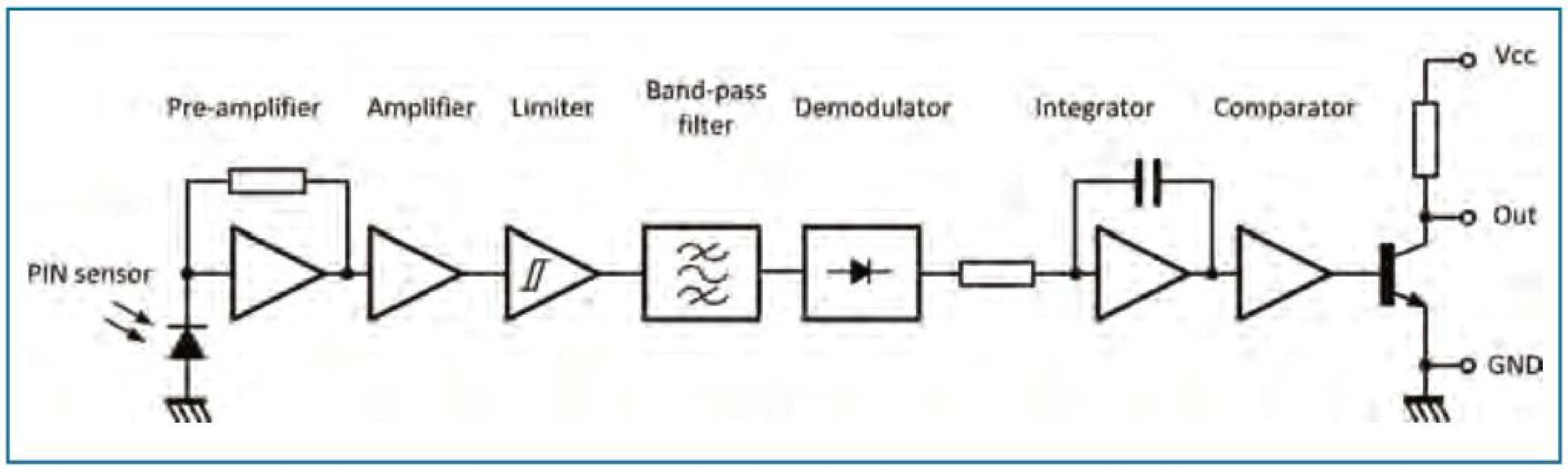


Fig.8.4. Internal schematic of a typical IR receiver

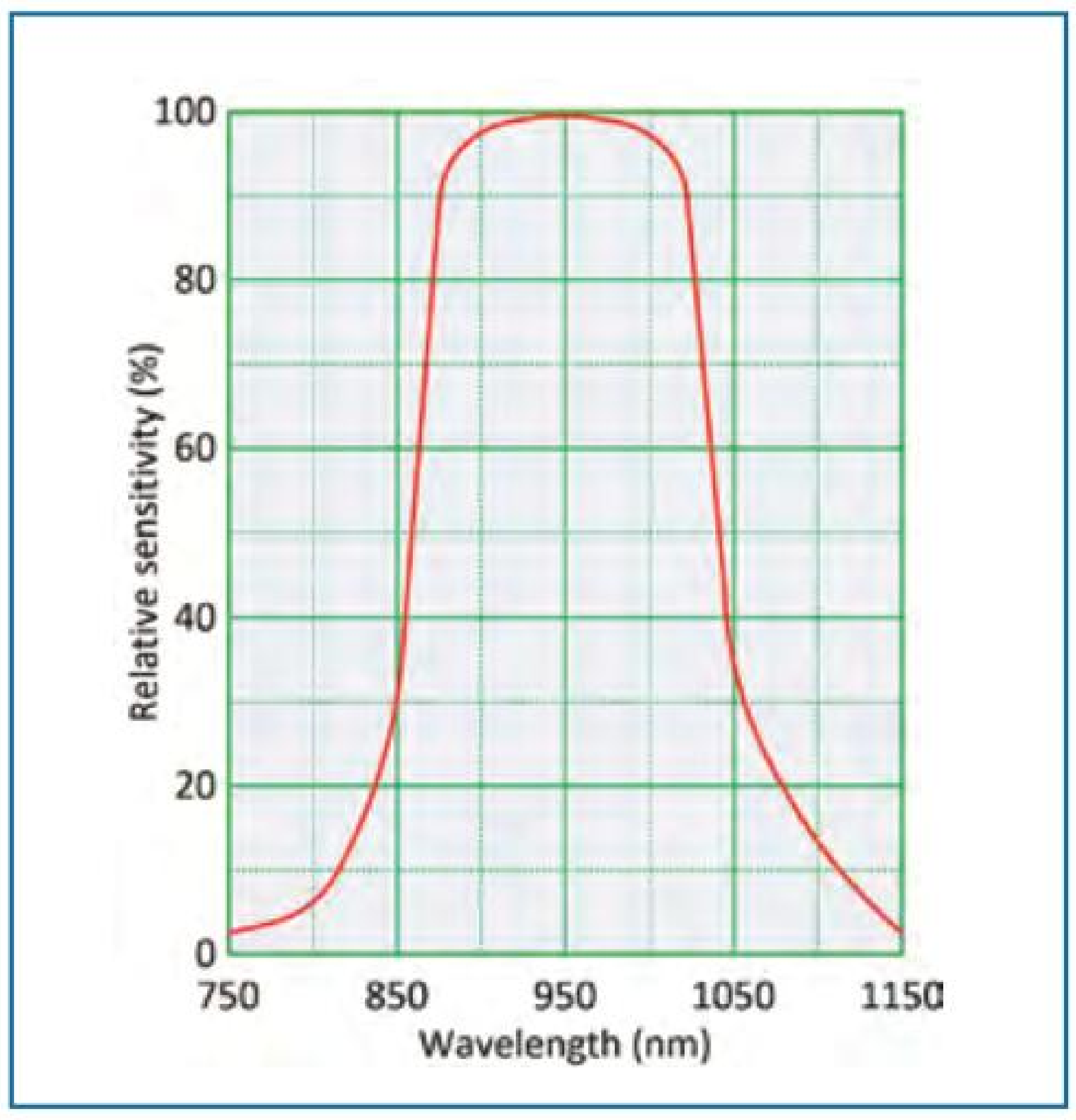


Fig.8.6. Spectral response of an AX-1838HS IR receiver

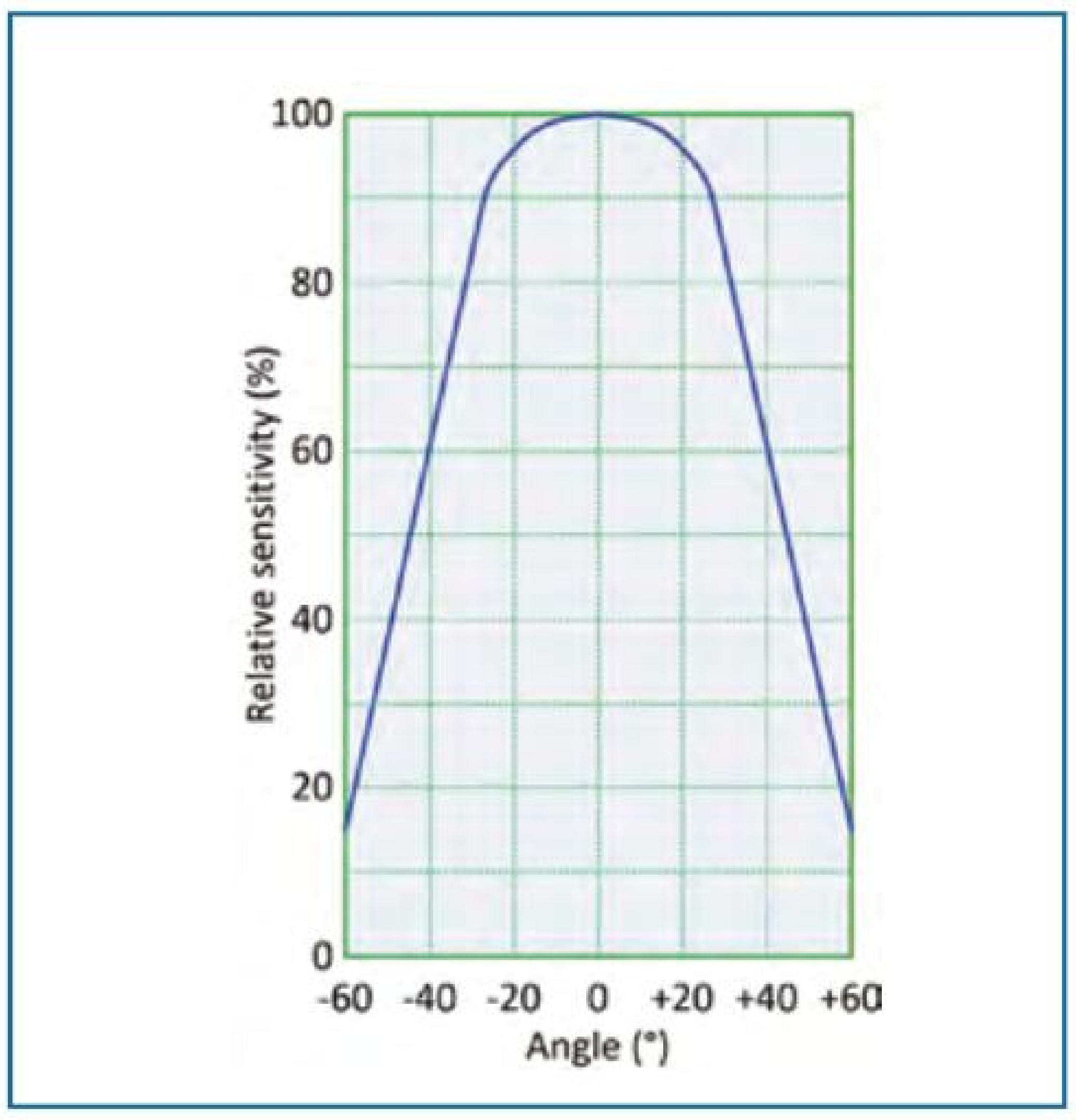


Fig.8.7. Angular response of an AX-1838HS IR receiver

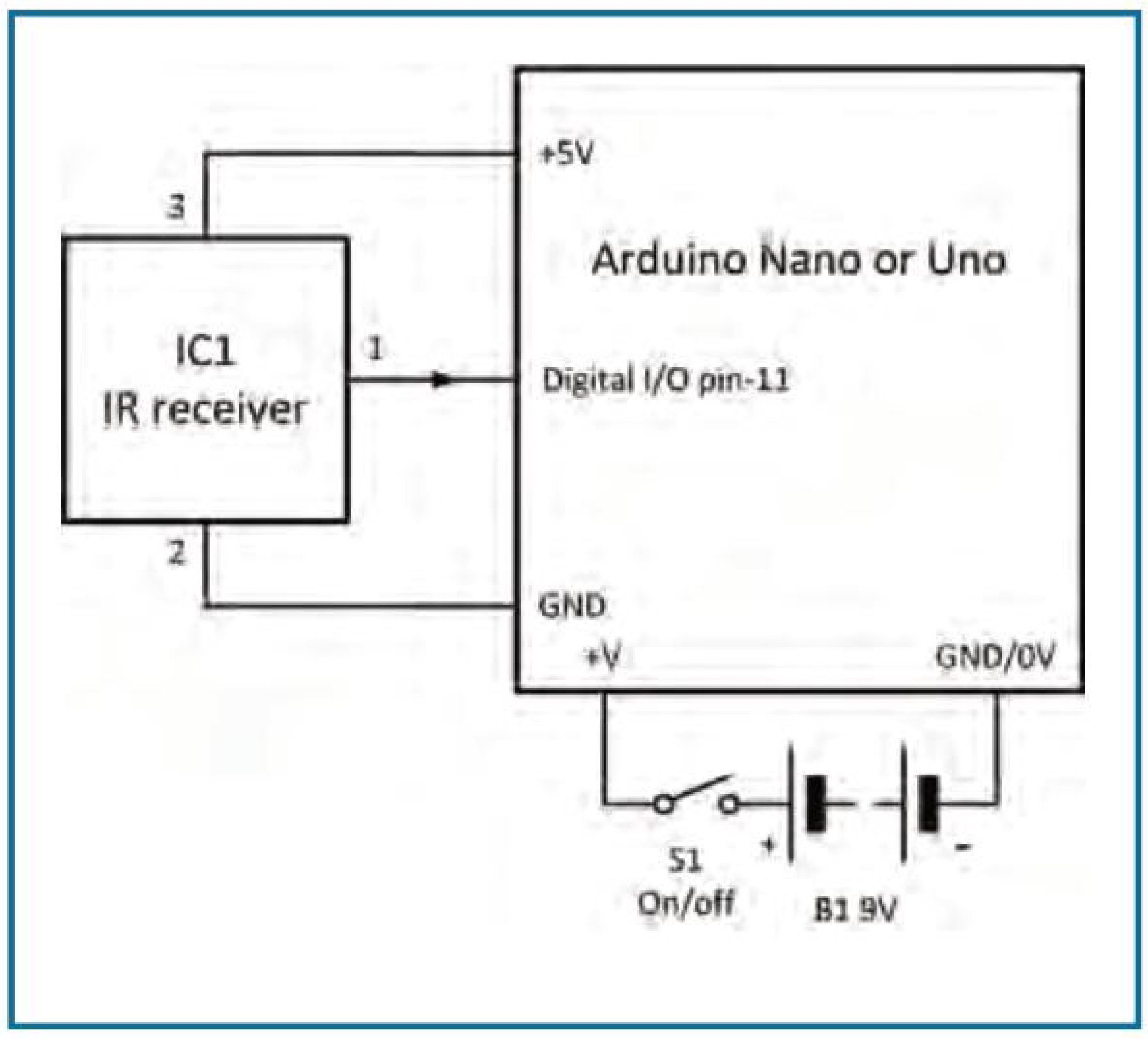


Fig.8.5. A typical IR receiver based on an Arduino

Timing

To understand the timing of the typical IR signal shown in Fig.8.10 it is important to realise that the basic unit of timing is 16 times that of the carrier period (ie, 16 × 27.8µs = 444µs). The time required to transmit a single bit (comprising a period in which both low and high states appear) is twice the basic unit of timing (888µs). As a result, the time required to send 20 bits of RC-6 data will be 40 times the basic time interval, amounting to about 17.8ms.

In the example shown in Fig.8.10, the header precedes the 20-bit block of data and it comprises a leader, start bit, three mode bits, and a trailer. The header is transmitted in a time period of 18 × 444µs = 8ms. Hence, a typical data word (comprising a header and 20-bit data followed by a period of 'signal-free time') will require about 30ms for transmission.

Header and trailer

Within the header, the relatively long leader can be used to permit automatic gain adjustment of the IR receiver, while the start bit is used as a timing reference. The next bits determine the mode used and in this example mb2 = 1, mb1 = 1 and mb0 = 0 corresponding to binary 110 or mode (the 'original equipment manufacturer' or OEM mode). The trailer bit (which is twice as long as any of the data bits) is used to terminate the header and can also be used to support a toggle action in which it is possible to distinguish between a newly pressed key and one which has been held down.

Data

The data bits can be configured into different fields according to the requirements of a particular application. For example, the first eight bits of a 20-bit data block (starting from the most significant bit or 'MSB') allow an 8-bit

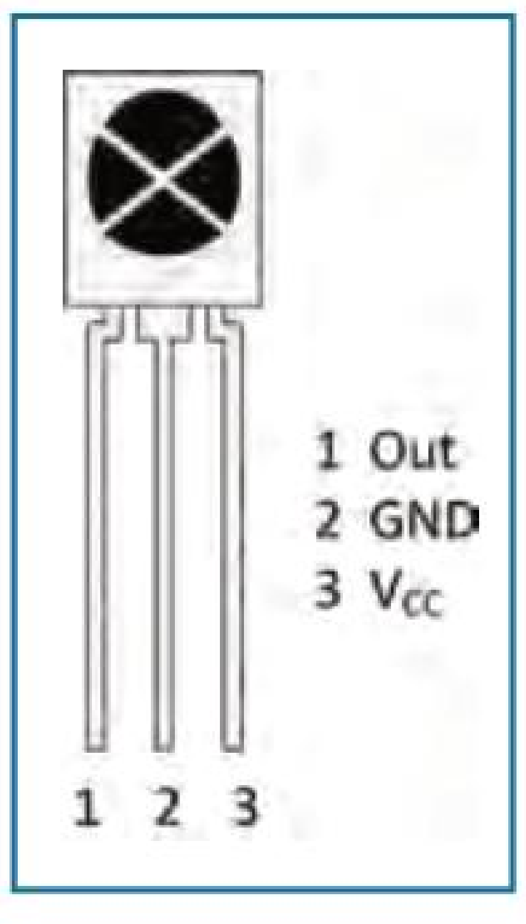


Fig.8.8. Pin connections for the AX-1838HS IR receiver

Table 8.1 Sky IR remote controller codes

Button	Data (hex)
0	C00000
1	C00001
2	C00002
3	C00003
4	C00004
5	C00005
6	C00006
7	C00007
8	C00008
9	C00009
on/off	C0000C
ch+	C00020
ch–	C00021
text	C0003C
up	C00058
down	C00059
left	C0005A
right	C0005B
select	C0005C
red	C0006D
green	C0006E
yellow	C0006F
blue	C00070
box office	C0007D
services	C0007E
sky	C00080
help	C00081
backup	C00083
i	C000CB
tv guide	C000CC
interactive	C000F5

address to be included (catering for a total of 256 possible devices) followed by a 4-bit control field followed by 8-bits representing the code to be transmitted, ending with the least significant bit, 'LSB'. Fig.8.10 shows the RC-6 transmitted data for a hexadecimal data value of 00001. This would correspond to an address field of 0, a control value of 0, and finally a transmitted code of 1. When using the RC-6 protocol for your own remote control applications you are, of course, free to define your own coding convention and make use of whatever data fields you feel might be appropriate. For reference, the codes generated by a standard Sky remote controller are listed in Table 8.1.

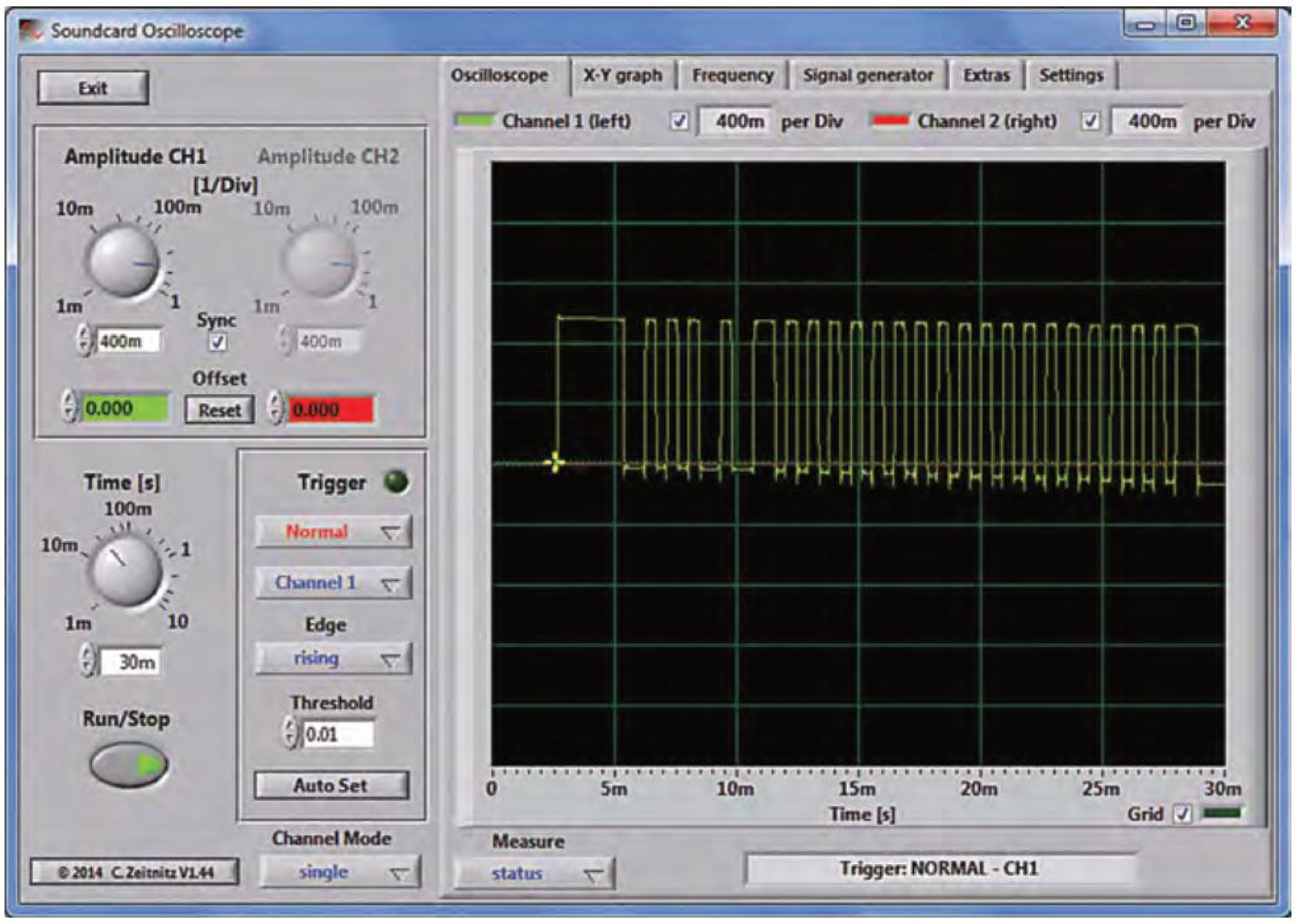

Soundcard Oscilloscope
Exit
Oscilloscope
X-Y graph
Frequency
Signal generator
Extras
Settings
Channel 1 (left)
400m per Div
Channel 2 (right)
400m per Div
Amplitude CH1
Amplitude CH2
[1/Div]
10m
100m
1m
1
Sync
400m
Offset
0.000
Reset
0.000
Time [s]
100m
10m
1
1m
10
30m
Run/Stop
Trigger
Normal
Channel 1
Edge
rising
Threshold
0.01
Auto Set
Channel Mode
single
© 2014 C.Zeitnitz V1.44
Measure
status
Trigger: NORMAL - CH1
0
5m
10m
15m
20m
25m
30m
Time [s]
Grid

Fig.8.9. Waveform of the output of a typical IR receiver

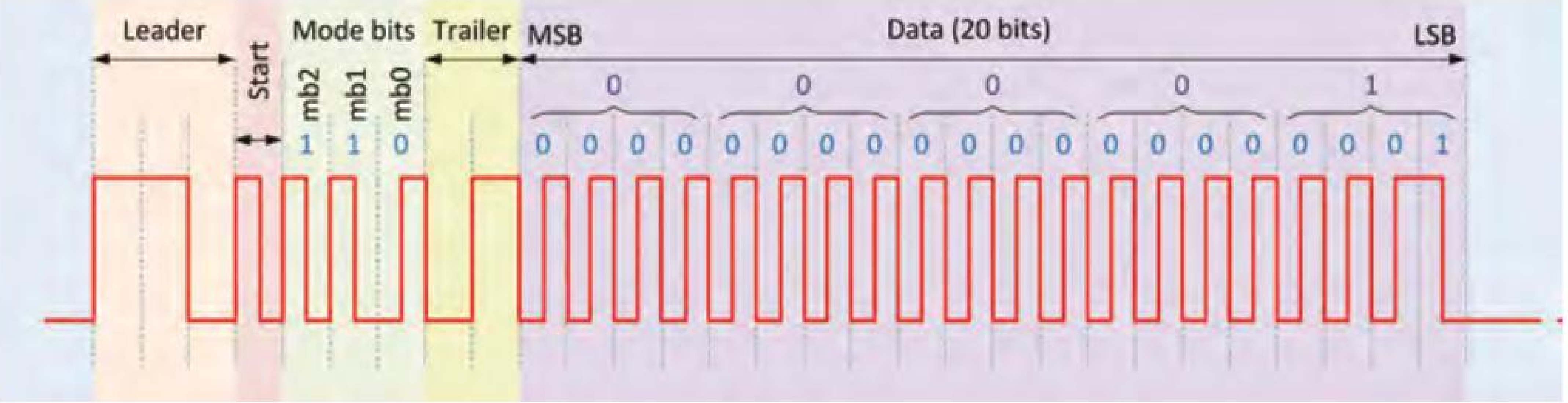

Leader
Start
Mode bits
mb2
mb1
mb0
1
1
0
Trailer
MSB
Data (20 bits)
LSB
0
0
0
0
1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1

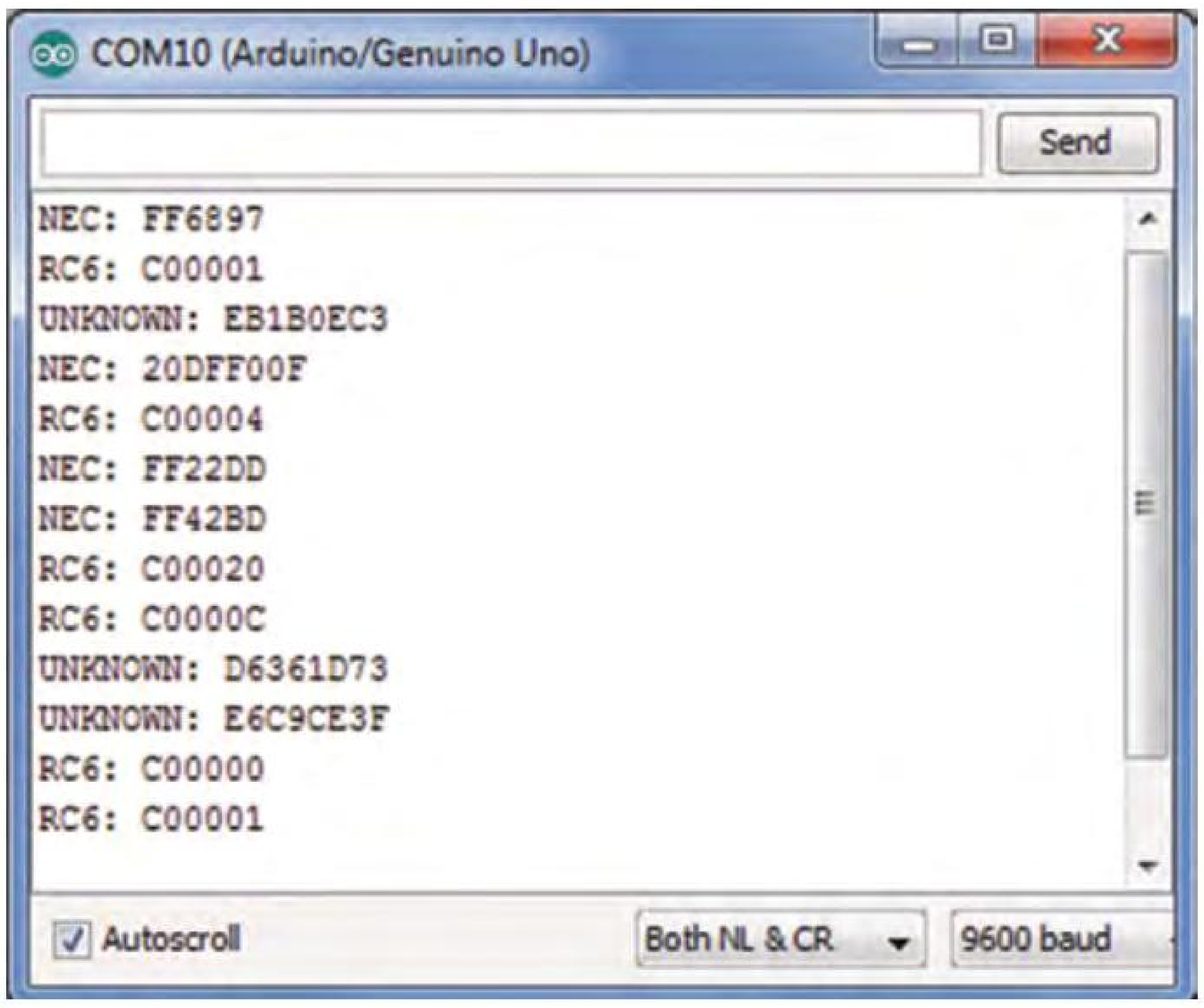
Fig.8.10. Data fields within the waveform shown in Fig.8.9 (see text)

Coding Quickstart : IR library

The Arduino's comprehensive IR library, `IRremote` was developed by Ken Shirriff and it can be used to both encode and decode IR signals that are compatible with a wide variety of IR remote controllers. Significantly, `IRremote` provides library facilities that can be used for both sending and receiving data using IR. In the case of sending you will need to know the codes for the device that you wish to control, while for receiving you will need to know the codes that are generated by your remote control keypad. Fortunately, it is very easy to obtain the codes for any particular keypad by using an IR receiver and some simple code (see Listing 8.1) that displays the results using the Arduino's serial port monitor. Simply pressing the buttons on the remote control will yield the codes that you need to know. A typical serial monitor display showing the codes received from several different IR controllers is shown in Fig.8.11.

Using the IR receiver object

To use an IR receiver from within your Arduino code receiver in C you will first need to create a receiver object using the `IRrecv` function, which allows you to define the Arduino pin that has been connected to the IR receiver. So, for example, if pin-11 is connected to the


COM10 (Arduino/Genuino Uno)
Send
☑ Autoscroll
Both NL & CR
9600 baud

```
NEC: FF6897
RC6: C00001
UNKNOWN: EB1B0EC3
NEC: 20DFF00F
RC6: C00004
NEC: FF22DD
NEC: FF42BD
RC6: C00020
RC6: C0000C
UNKNOWN: D6361D73
UNKNOWN: E6C9CE3F
RC6: C00000
RC6: C00001
```

Fig.8.11. A typical serial monitor display showing the received codes obtained from several different handheld remote controllers

Table 8.2 Properties of the received code

Function	Use
`results.decode_type`	Indicates controller type (NEC, RC5, RC6, SONY or UNKNOWN)
`results.value`	IR code received (or 0 if the type of controller is UNKNOWN)
`results.bits`	Number of bits used in the code
`results.rawbuf`	An array containing the IR pulse times
`results.rawlen`	Number of items stored in the array

output of an IR receiver you would need to include a statement of the form:

```
IRrecv irrecv(11); // IR receiver connected to pin-11
```

Alternatively, it would be better practice to define a constant to refer to the pin as follows:

```
const int ReceivePin = 11; // Receive to pin-11
IRrecv irrecv(ReceivePin);
```

When you are ready to start receiving data you will need to enable a timer interrupt with a line like this:

```
irrecv.enableIRIn()
```

Next, to attempt to receive and decode the received data you will need to use:

```
irrecv.decode(&results)
```

This function returns 'true' if a code has been received, otherwise it will return 'false'. The received code is passed by **reference** to results (note the & that precedes `results` passes the address of `results` rather than the value itself). Once the code has been passed, various properties can be examined, including the type of controller used to generate the code and the number of bits used in the code as well as the code itself (see Table 8.2).

Once a code has been received it will be necessary to reset the IR receiver so that it is ready to receive the next code. This is achieved using:

```
irrecv.resume();
```

Finally, a visual indication can be a useful aid to troubleshooting and also a means of indicating that IR data is being received. To flash the Arduino's LED (pin-13) you just need to add the following line of code:

```
irrecv.blink13(true);
```

Using the IR transmitter object

Transmitting an IR code is also quite straightforward. First you will need to create a transmitter object in your code. This is achieved by means of a command like this:

```
IRsend irsend;
```

Sending data via IR

To send a code you will need to make use of the `irsend` function that's specific to the data format that will be recognised by the device that you are controlling. Table 8.3 shows the different formats that can be used to send IR data. Note how two parameters must be passed in each case. The first parameter is the code to be sent, while the second is the number of bits used in the code.

So, for example, to send a hex code of 001 using 12 bits and RC6 protocol you could use:

```
irsend.sendRC6(0x001, 12);
```

Alternatively, to send a hex code of 6EA01 using 20 bits and NEC protocol you could use:

```
irsend.sendNEC(0x6EA01, 20);
```

To ensure that your data is received it might be preferable to send your data several times in succession, as shown in Listing 8.2. Here an RC6 hex code of 00F is sent using 12 bits four times in quick succession with a delay of four seconds between bursts of IR data. This routine will provide you with a simple means of testing an IR transmitter in conjunction with a second Arduino running the code that you met earlier in Listing 8.1. Note that the Uno's pin-3 is used for transmitting IR data (see Fig. 8.1) as this pin supports the required pulse-width modulation (PWM) of the output data string.

Sending raw codes

As a bonus, Ken Shirriff's excellent IR library allows you to send data in the form of raw code without a

Table 8.3 Different formats in which IR data can be sent

IR data format	Function
RC5	`irsend.sendRC5(IRcode, numBits)`
RC6	`irsend.sendRC6(IRcode, numBits)`
NEC	`irsend.sendNEC(IRcode, numBits)`
Sony	`irsend.sendSony(IRcode, numBits)`

Listing 8.1 Using the Arduino's serial monitor to view the codes generated by a handheld remote controller

```
#include <IRremote.h>
const int RECV_PIN = 11; // Connect the IR receiver to pin-11
IRrecv irrecv(RECV_PIN);
decode_results results;

void setup()
{
  Serial.begin(9600);
  irrecv.enableIRIn();   // Start the IR receiver
  irrecv.blink13(true);  // Blink the on-board LED to confirm
}

void loop() {
  if (irrecv.decode(&results)) {
    // Attempt to detect the type of remote controller used
    if (results.decode_type == NEC) {
      Serial.print("NEC: ");
    } else if (results.decode_type == SONY) {
      Serial.print("SONY: ");
    } else if (results.decode_type == RC5) {
      Serial.print("RC5: ");
    } else if (results.decode_type == RC6) {
      Serial.print("RC6: ");
    } else if (results.decode_type == UNKNOWN) {
      Serial.print("UNKNOWN: ");
    }
    Serial.println(results.value, HEX);
    irrecv.resume(); // Receive the next value
  }
}
```

specified controller. You can do this by including a statement of the form:

```
irsend.sendRaw(rawbuf, rawlen, frequency);
```

This is just a little trickier because it usually involves first using a receiver to determine the expected values of `rawbuf` and `rawlen` (you may have to do this several times in order to obtain a consistent result). The frequency parameter relates to the bandpass filter used in the receiver. The value is usually expressed in kHz and is often 36 or 38 (see earlier). For further information you should refer to the examples that are included in the IR library package.

Listing 8.2 Simple Arduino IR transmitter test code

```
#include <IRremote.h>

IRsend irsend;

void setup() {
   // Initialize the Arduino's LED on pin-13
   pinMode(13, OUTPUT);
}

void loop() {
  for (int i = 1; i < 5; i++) {
    // Send IR code four times using RC6 protocol
    irsend.sendRC6(0x001, 12);
    delay(50); // Short delay
  }
  // Wait 4 seconds before sending again and
  // blink the Arduino's LED to confirm sending
  digitalWrite(13, HIGH);
  delay(2000);
  digitalWrite(13, LOW);
  delay(2000);
}
```

Get Real : IR power controller

In this month's *Get Real* we will be describing a handy device that can receive signals from a conventional handheld remote controller and use them to switch the power delivered to a maximum of eight external loads. The complete circuit of the IR power controller is shown in Fig.8.12. The power controller comprises three separate modules. The first of these is a small IR receiver, which can be either purchased as a ready-made module (see Fig.8.13) or can be quickly and easily built on a small piece of stripboard (see Figs.8.14 and 8.15). The second module is the Arduino Uno or Nano, and the third is an inexpensive eight-channel relay board. Note that these modules are nowadays available at such minimal cost that it is simply not worth attempting to build one from scratch. The complete eight-channel IR power controller is shown, together with a home-built IR receiver module, in Fig.8.16.

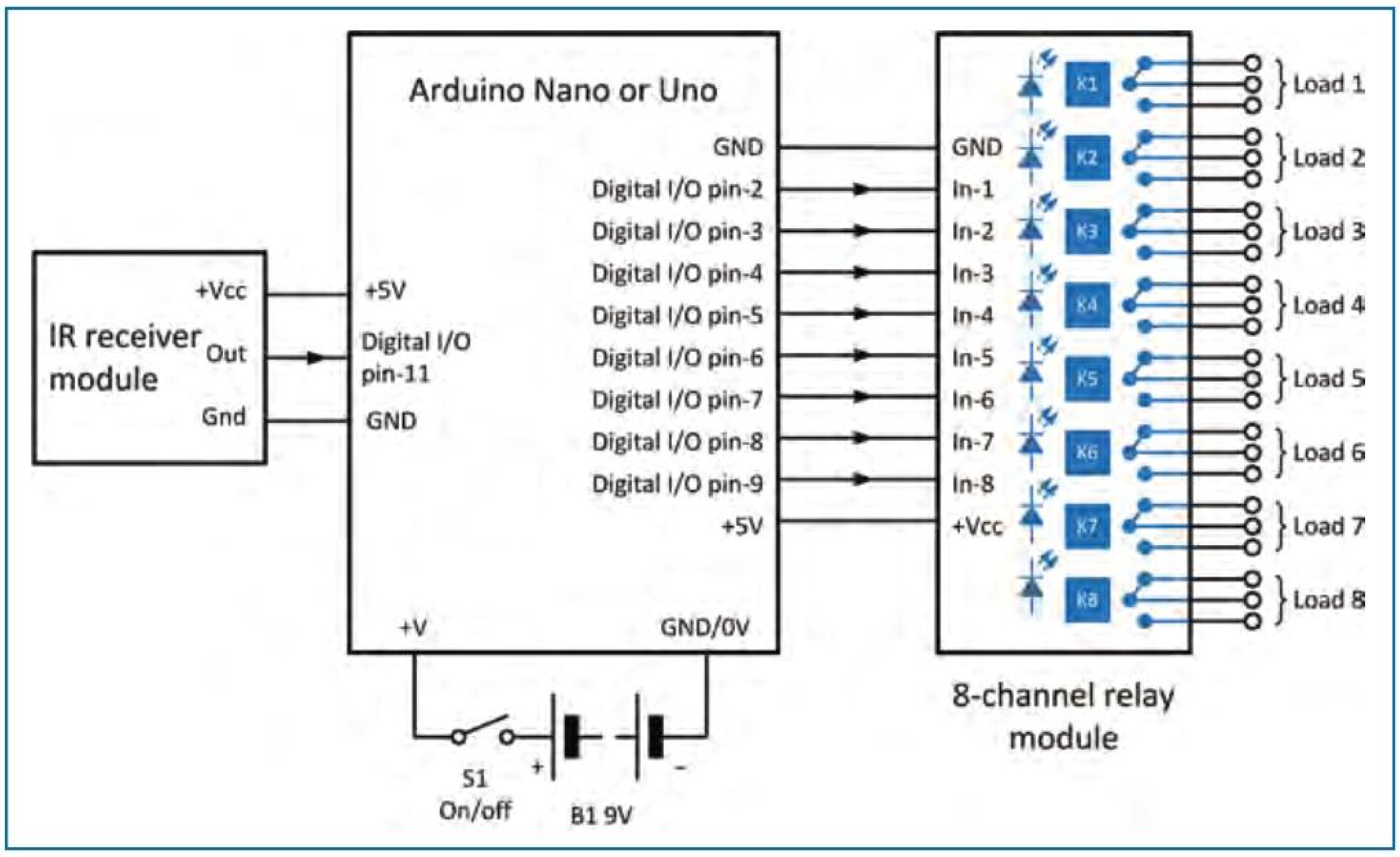

Arduino Nano or Uno
GND
Digital I/O pin-2
Digital I/O pin-3
Digital I/O pin-4
Digital I/O pin-5
Digital I/O pin-6
Digital I/O pin-7
Digital I/O pin-8
Digital I/O pin-9
+5V
+5V
Digital I/O pin-11
GND
+V
GND/0V
IR receiver module
+Vcc
Out
Gnd
GND
In-1
In-2
In-3
In-4
In-5
In-6
In-7
In-8
+Vcc
K1
K2
K3
K4
K5
K6
K7
K8
Load 1
Load 2
Load 3
Load 4
Load 5
Load 6
Load 7
Load 8
8-channel relay module
S1
On/off
B1 9V
+
-

Fig.8.12. Complete circuit of IR power controller

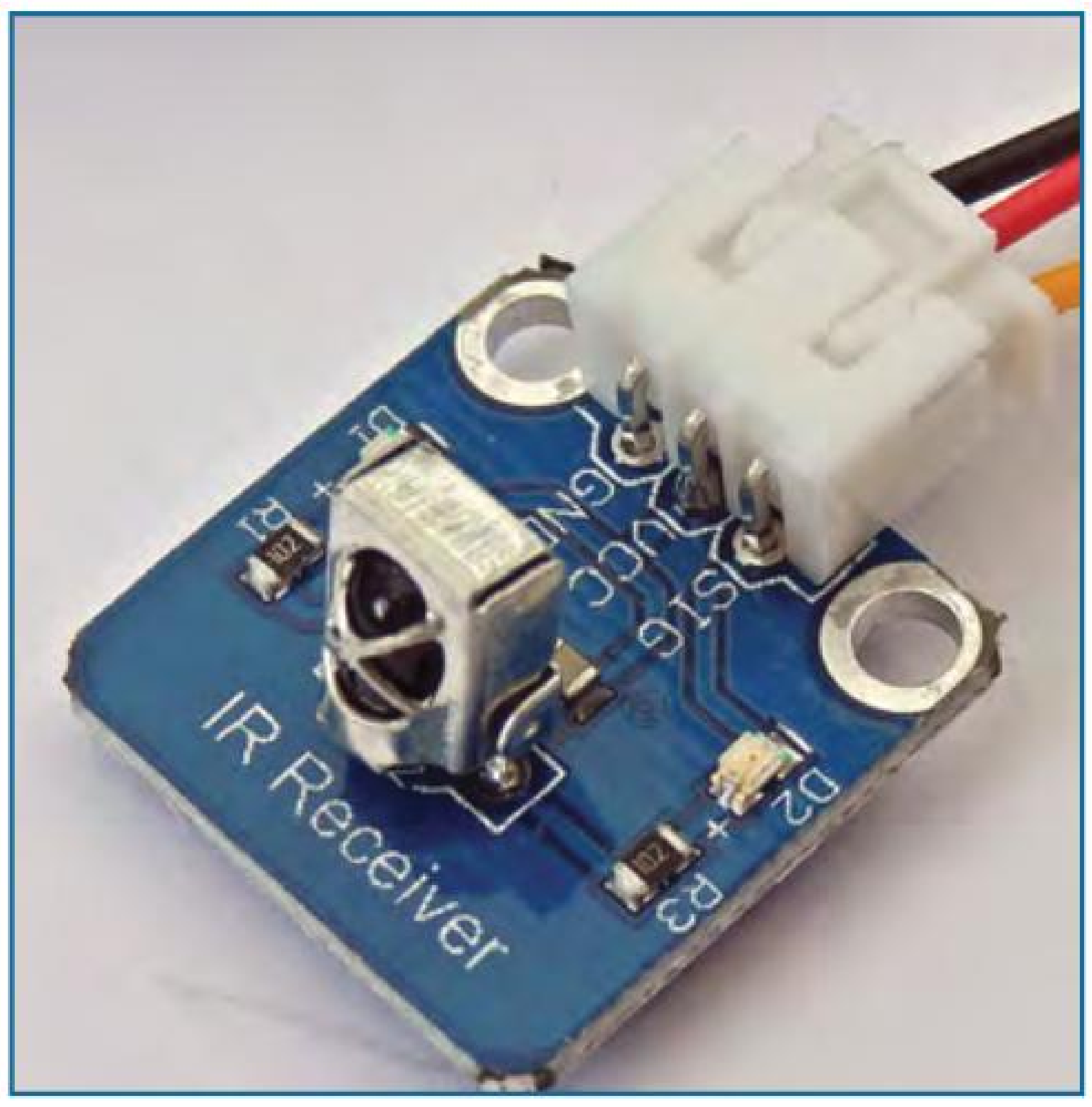

IR Receiver
GND
VCC
SIG
D1
R1
D2
R3

Fig.8.13. Low-cost IR receiver module

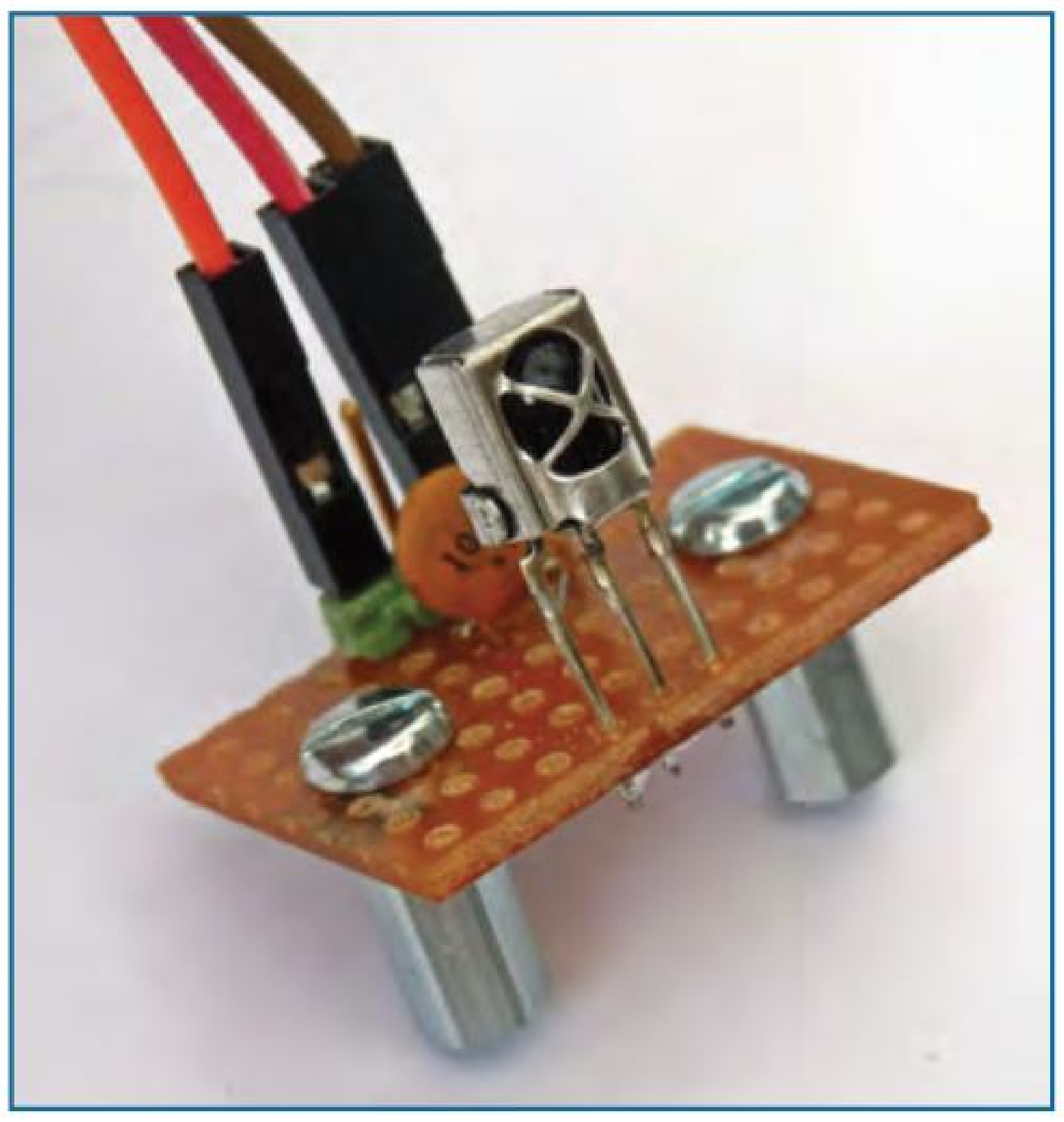


Fig.8.14. Home-built IR receiver module

You will need

Arduino Nano or Uno microcontroller (*see text*)
USB cable with miniature-USB connector (for programming only)
Computer with an available powered USB port (for programming only)
1 low-cost IR receiver module (see text)
1 100nF ceramic disc capacitor, C1 (not required if using a pre-built module)
1 AX-1838HS (or similar IR) receiver (not required if using a pre-built module)
1 9V battery, B1
1 single-pole, single-throw (SPST) switch, S1
1 small piece of stripboard (not required if using a pre-built module)
1 10-way and 1 3-way ribbon cable jumpers
1 low-cost remote controller (a surplus Sky remote is ideal).

Remote

The handheld remote controller can be almost any low-cost or surplus unit. We

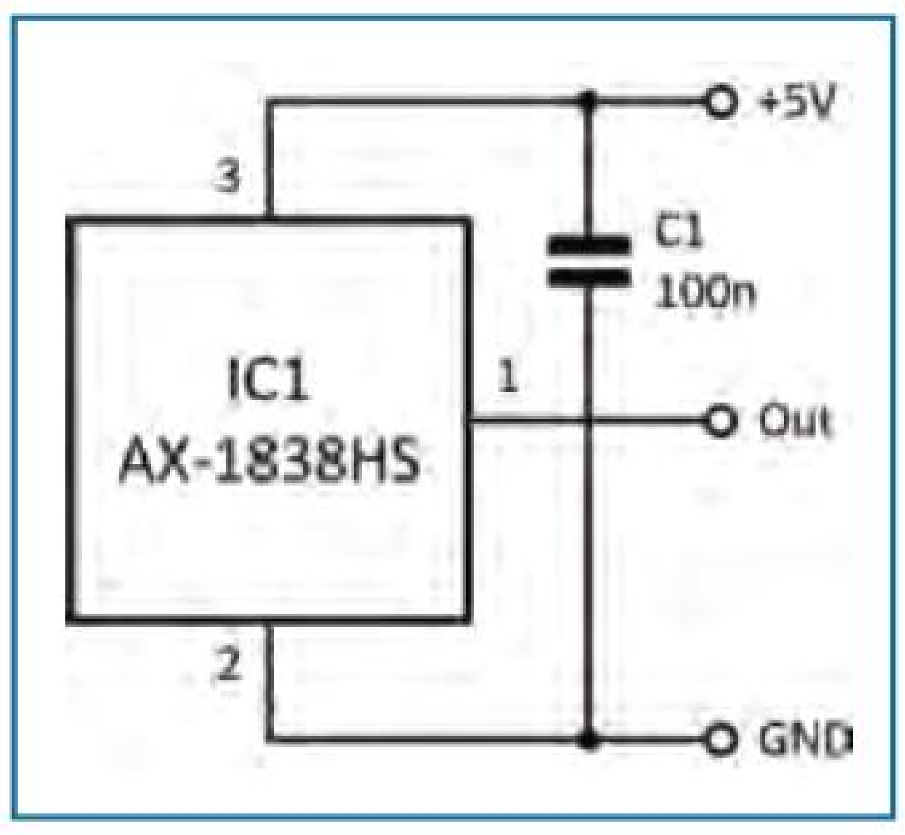

+5V
3
C1
100n
IC1
AX-1838HS
1
Out
2
GND

Fig.8.15. Circuit of the home-built IR receiver module

used a standard Sky remote in our prototype – but, provided that you make the necessary changes to the program code, you can use anything that you have to hand. If you need to determine the codes that an unknown remote controller is sending you can make use of Listing 8.1 before finalising your program code.

Code

The complete code for the eight-channel IR power controller is shown in Listing 8.3. The code is straightforward and, as usual, we've liberally commented it in order to help you understand what's going on. The code requires the `IRremote` library (see earlier). This can be installed from within the Arduino's IDE by selecting Sketch from the drop-down menu followed by Include, Library, and Manage Libraries. Enter 'irremote' in the search field and, when you have located it, click on the Install button to download and install the library.

The unique codes to be used for the eight power controller channels are stored in the `code[]` array. The codes are entered in hexadecimal format and those shown in the listing are for a standard Sky remote. They will need to be changed if you are using a different hand-held remote controller. If in doubt, it is well worth checking the codes that your remote is actually sending (as described earlier) and using these to populate the array. The position in the array corresponds directly to the power controller channel. Thus, the first hexadecimal value is the code for channel 1, and so on. Two further buttons have been defined. These are used for simultaneously setting or resetting all of the outputs. Note that the `setup()` code places all of the outputs in the 'off' state before entering the main loop.

As with our previous *Get Real* projects, the code should first be entered into the IDE and then saved before compiling and uploading it to the Uno, as described in last month's *Arduino Workshop*. When you have debugged and corrected your code don't forget to save it by clicking on 'File' and 'Save' or 'Save As…'. Next click on 'Sketch' and 'Verify/Compile'. Any compilation errors will then be reported in the window at the bottom of the IDE.

Testing and adjustment

When you've corrected any coding errors that the compiler reports you will be ready to upload your code to the Uno or Nano. Just click on the upload arrow and watch the progress report. After the Nano performs a reset you should find that the eight channels on the relay module (1 to 8) can be toggled on and off by the corresponding eight buttons (1 to 8) on the remote controller. You should also find that the outputs can be simultaneously reset to 'off' by pressing the 'backup' button on the remote. Conversely, pressing the 'power on/off' button on the remote will simultaneously put all of the outputs 'on'.

Note that best results will usually be obtained with the remote controller held about 1.5 to 2.5m from the IR receiver and pointing directly towards it. The operational range will be significantly reduced when the remote controller is pointing

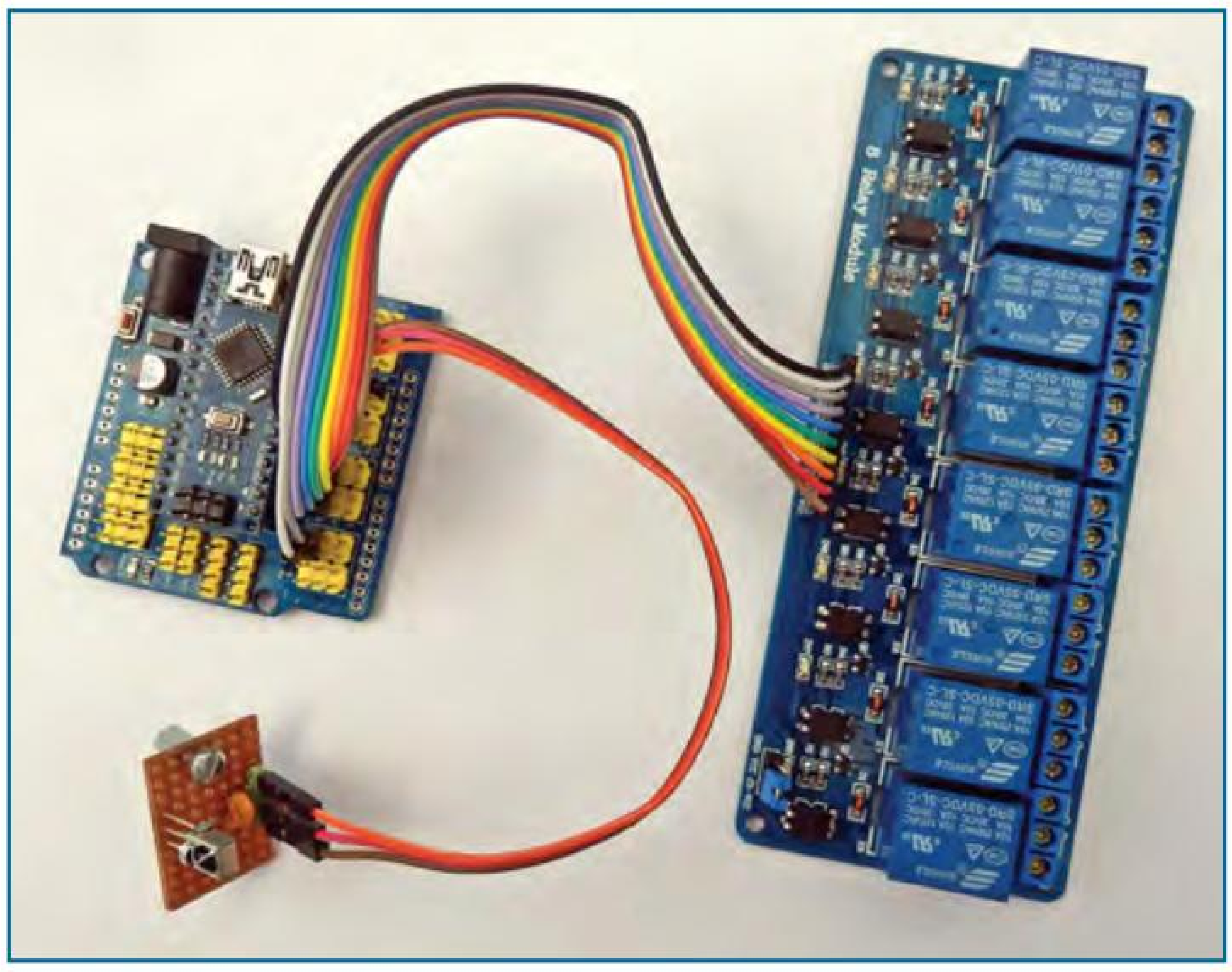


Fig.8.16. The complete IR power controller

Listing 8.3 Code for the IR power controller

```
/* 8-channel IR power controller for the Arduino Uno or Nano */

#include <IRremote.h> // Use the IR remote library

int RECV_PIN = 11;    // IR receiver on pin-11
IRrecv irrecv(RECV_PIN);
decode_results results;

float code[] = {0xC00001,0xC00002,0xC00003,0xC00004,0xC00005,0xC00006,
0xC00007,0xC00008};
float buttonAllOff = 0xC00083; // Backup button
float buttonAllOn = 0xC0000C;  // Power button

void setup()
{
  // Set up digital outputs for the relay board
  for (int n = 2; n < 10; n++)
     pinMode(n, OUTPUT);
  irrecv.enableIRIn(); // Start the receiver
  alloff(); // Start with all outputs off
}

void loop()
{
  // Main program loop checks the received code and acts upon it
  if (irrecv.decode(&results)) {
    for (int n = 2; n < 10; n++)
      if (results.value == code[n]) {
        digitalWrite(n, !digitalRead(n));
        delay(1000);
    }
    if (results.value == buttonAllOff) {
        // User wants to cancel all outputs
        alloff();
    }
    if (results.value == buttonAllOn) {
        // User wants to put all outputs on
        allon();
    }
    irrecv.resume(); // Receive the next value
  }
}

void alloff() {
for (int n = 2; n < 10; n++)
        digitalWrite(n, HIGH);
}

void allon() {
for (int n = 2; n < 10; n++)
        digitalWrite(n, LOW);
}
```

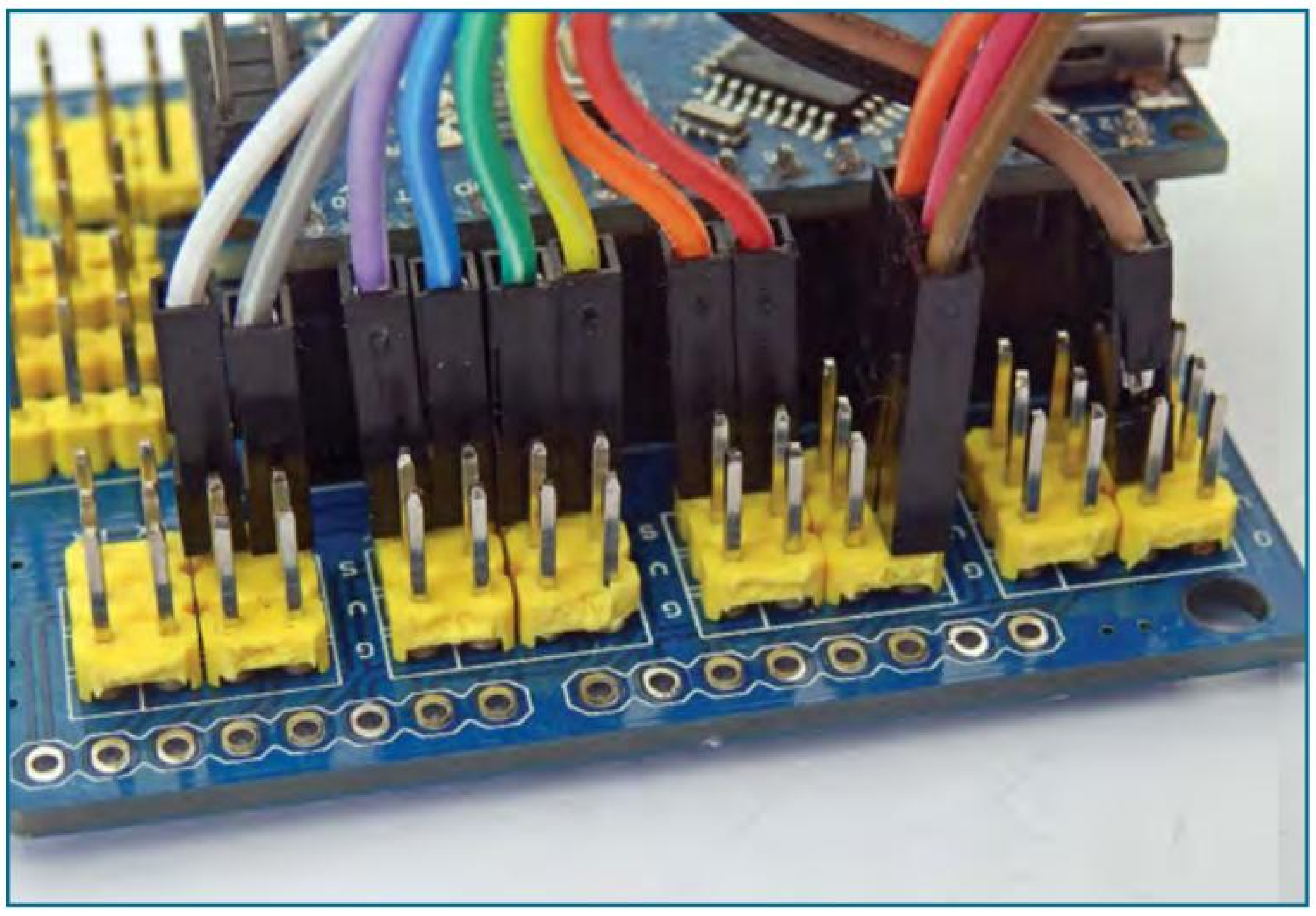


Fig.8.17. Wiring to the Nano prototyping board header

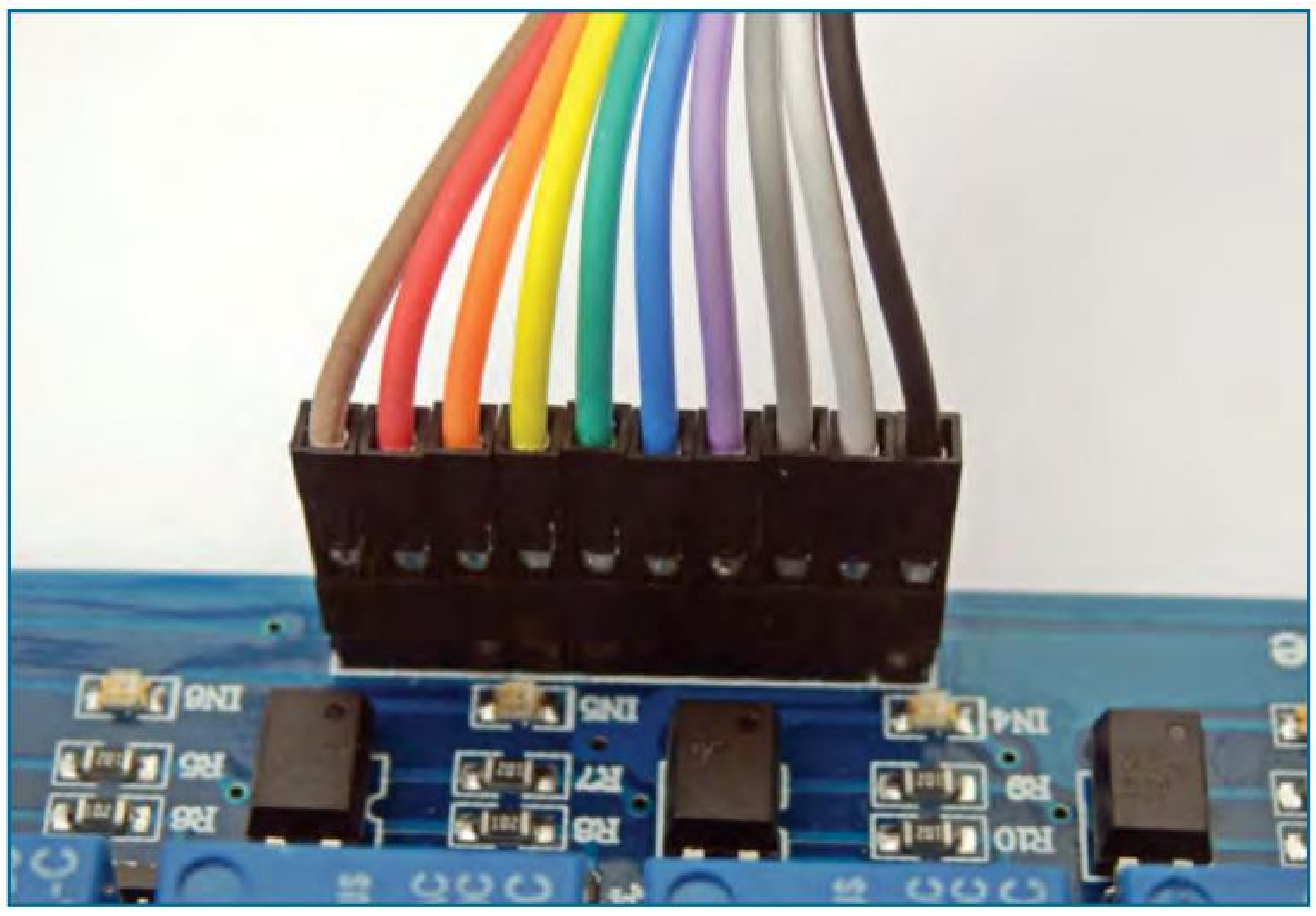


Fig.8.18. Wiring to the 8-channel relay module header

away from the IR receiver or when there are obstacles in the path between the receiver and the remote.

Going further

There's plenty of scope for going further with this month's *Get Real* project, eg:

- Expanding the output capability by adding further outputs
- Using some of the remaining buttons to perform different switching actions such as delayed on and off or switching an output 'on' for a fixed length of time
- Sequencing the outputs so that successive loads are switched on and off in turn.

These additions can be easily built into the basic IR power controller and will provide you with a great opportunity to further develop your coding skills.

Next month

In next month's *Teach-In 2016*, *Arduino World* will be looking at methods of connecting an Arduino to a local area network (LAN) and to the Internet using an Ethernet shield. *Arduino Workshop* will introduce you to the practical aspects of using an Ethernet connection to send and receive data using a standard router or hub fitted with an Ethernet port. Our programming feature, *Coding Quickstart*, introduces UDP and Network Time Protocol. Finally, our *Get Real* project will describe the design and construction of a highly accurate Internet-connected clock.

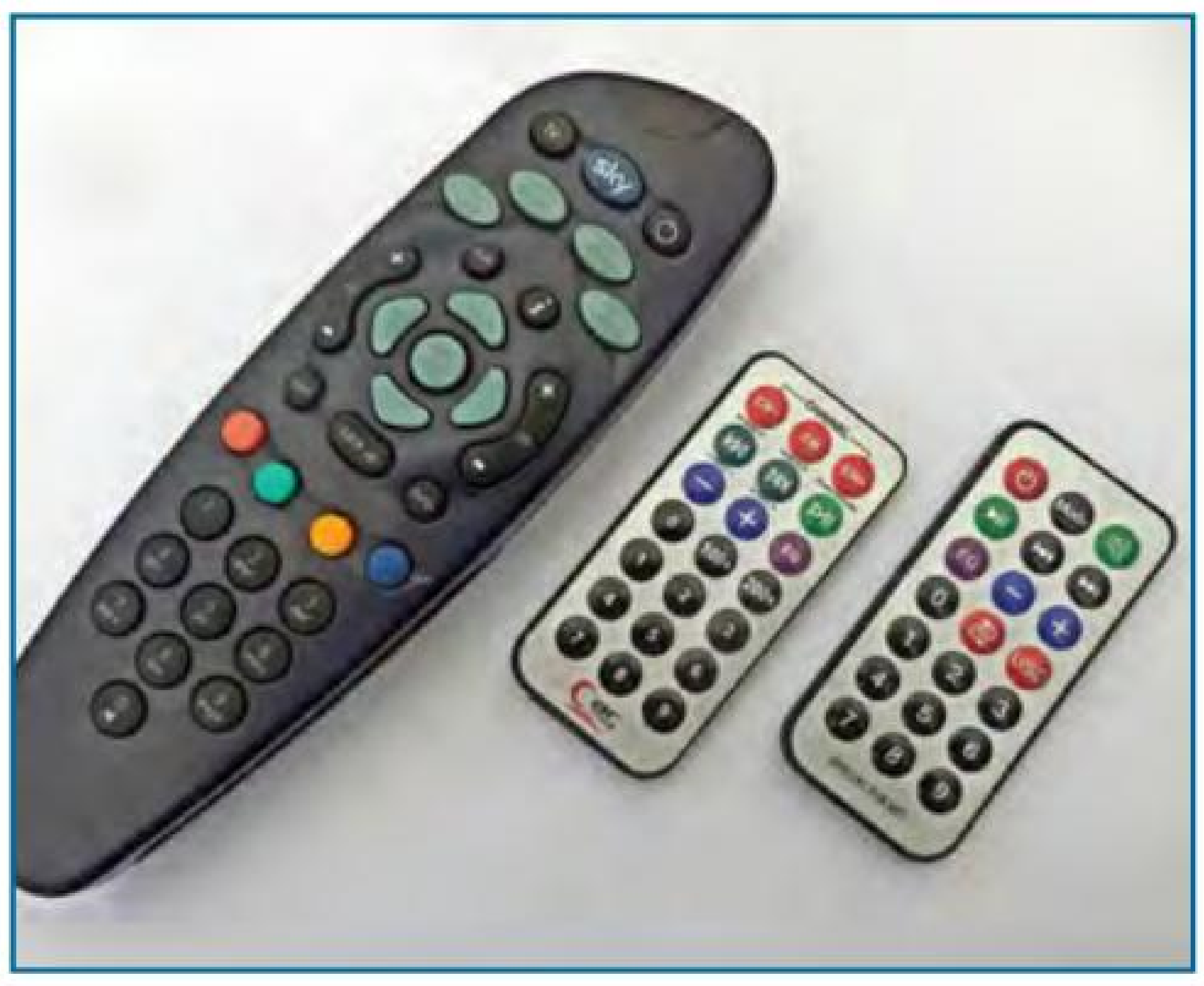


Fig.8.19. Typical hand-held remote controllers (the two inexpensive units on the right are available from eBay and other suppliers)

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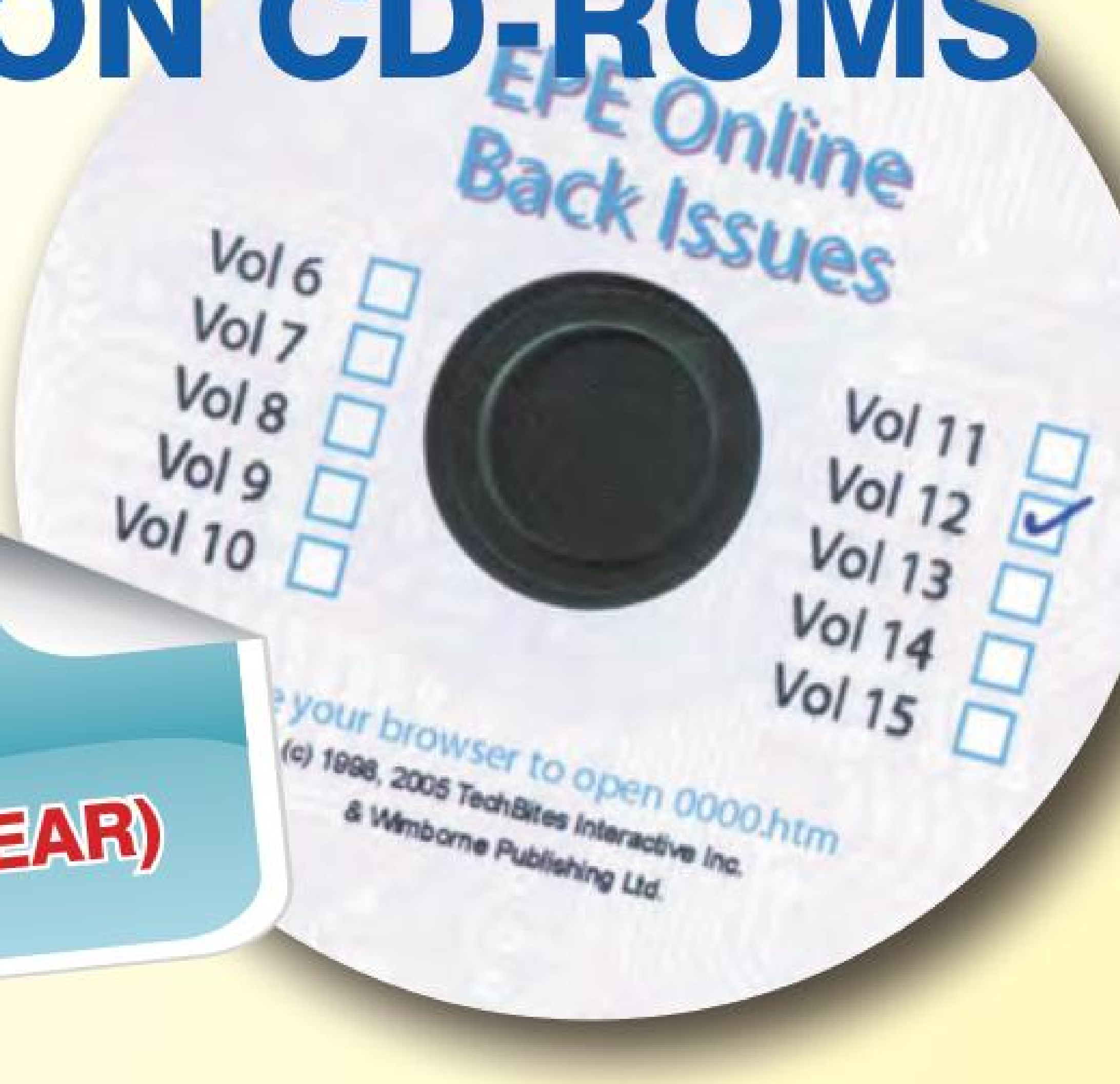
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NET WORK

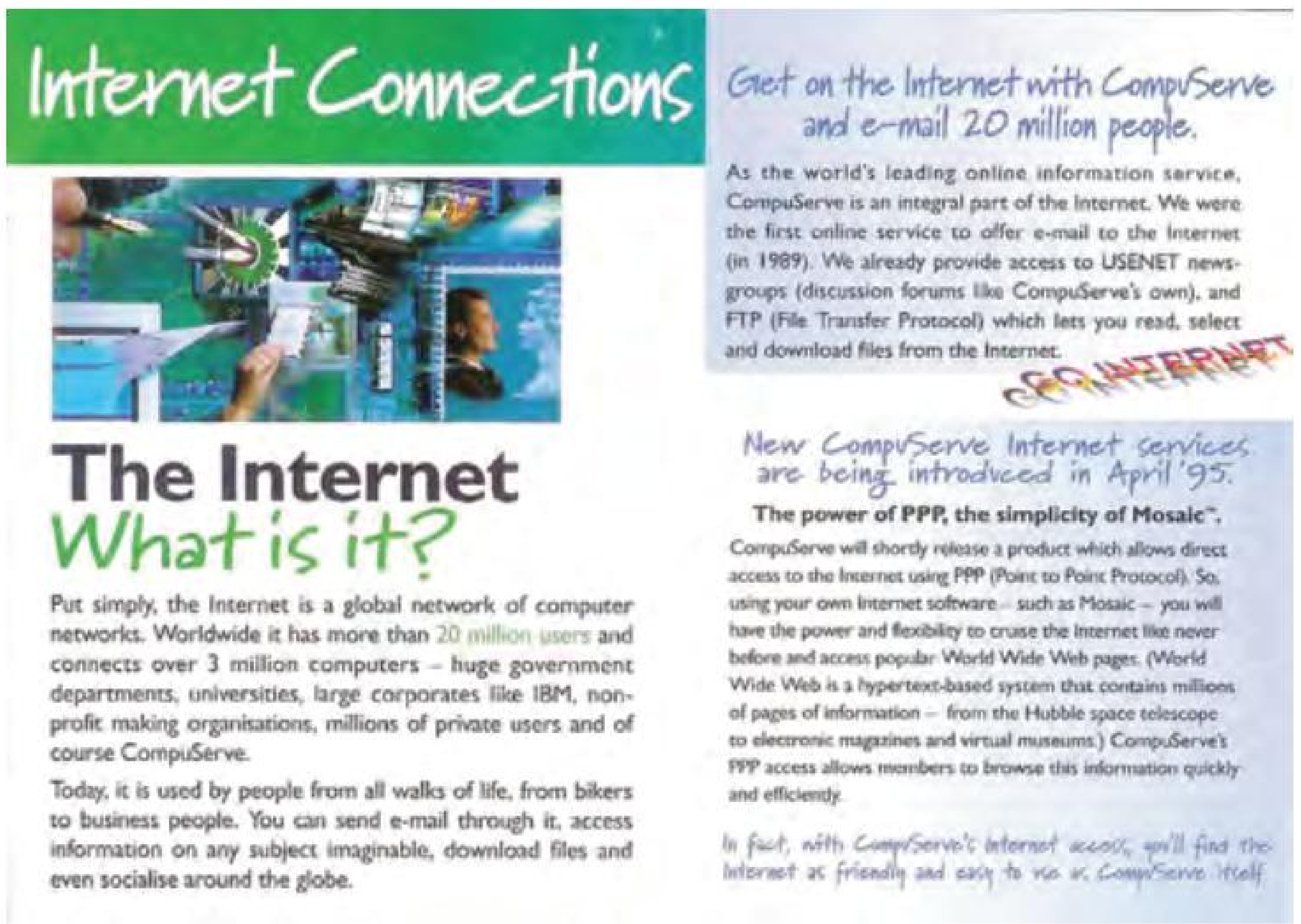
by Alan Winstanley

Uh-oh, here come the crowds

WELCOME to the second part of a *Net Work* special feature that charts the evolution of the Internet, as seen from my British perspective. Last month, I wrote how in the 1990s Internet services were still in their infancy, and providers such as CompuServe offered a 'global information service that was accessible via a local phone call in most major European cities'. To give readers a flavour of what life was like at that time, there was little to compare with CompuServe's curated service but it did not come cheap: for £6.50 / $9.95 a month plus phone call costs, subscribers enjoyed a heady allowance of up to 90 email messages per *month*, and with a wheezy 28.8k modem they could check news, weather, travel, hotels, stocks, theatre reviews and more besides. Users 'went' to basic free services such as GO UKPUBS or GO UKSOAPS and customers were stuck with machine-friendly email addresses such as 10537,1234@compuserve.com. To save costs, messages could be downloaded and read offline.

Optional 'Extended Services' cost 5p per minute extra and high-end 'Premium Services' delivered more valuable data to the subscriber's desktop: a typical company report, for example, might cost between £5-£10. CompuServe offered high quality and squeaky-clean services that were heavily managed and users were herded away from the 'Wild West' of raw Internet access. There was no escaping the fact that the 'net itself was growing fast, though, and users were soon champing at the bit to harness *external* services such as Usenet and the novelty of websites. So a CompuServe leaflet of the time (1995) included a section headed *The Internet – what is it*?, to guide anyone thinking of peeping over the garden wall. It trumpeted 'Word Wide Web coming soon' and 'Avoid the crowds and check out scores of leading UK and US shops online – UK Shopping starts Spring '95'. Web browsing had yet to go mainstream; however, subscribers would soon be able to use a new program called Mosaic to 'cruise the Internet like never before and access World Wide Web pages' as Internet fever took hold. There would be plenty of over-riders along the way, as CompuServe disclaimed all responsibility and users 'cruised' that nasty Internet at their own risk. Interesting times!

In those evolutionary days, London-based CIX (Compulink Information eXchange) was a major members-only discussion area populated by all manner of professional types. Other than CompuServe or CIX, Usenet (or 'News') was a key way of exchanging comments and opinions between like-minded subscribers. Originating from the 1980s, topical Usenet newsgroups (a precursor to forums) such as **sci.electronics** were home to many academics, professionals and enthusiasts at the time. I made many online friends this way, including our own Clive Maxfield, who still writes for *EPE* today. So-called newsfeeds were offered by a few ISPs such as the upstart Demon Internet and Claranet, and 'newsreader' software (DOS-based in my case) enabled threaded Usenet discussions to be followed, posting a message and downloading follow-up comments a few days later. There was no rush for immediacy and life online was productive, satisfying and mostly enjoyable at this time. The flip-side of posting into Usenet newsgroups was the public exposure given to one's email address: these were soon targeted by marketers who became responsible for the Internet's biggest scourge – spam email.


GO INTERNET

Internet Connections

The Internet
What is it?

Put simply, the Internet is a global network of computer networks. Worldwide it has more than 20 million users and connects over 3 million computers – huge government departments, universities, large corporates like IBM, non-profit making organisations, millions of private users and of course CompuServe.

Today, it is used by people from all walks of life, from bikers to business people. You can send e-mail through it, access information on any subject imaginable, download files and even socialise around the globe.

Get on the Internet with CompuServe and e-mail 20 million people.

As the world's leading online information service, CompuServe is an integral part of the Internet. We were the first online service to offer e-mail to the Internet (in 1989). We already provide access to USENET newsgroups (discussion forums like CompuServe's own), and FTP (File Transfer Protocol) which lets you read, select and download files from the Internet.

New CompuServe Internet services are being introduced in April '95.

The power of PPP, the simplicity of Mosaic™.

CompuServe will shortly release a product which allows direct access to the Internet using PPP (Point to Point Protocol). So, using your own Internet software – such as Mosaic – you will have the power and flexibility to cruise the Internet like never before and access popular World Wide Web pages. (World Wide Web is a hypertext-based system that contains millions of pages of information – from the Hubble space telescope to electronic magazines and virtual museums.) CompuServe's PPP access allows members to browse this information quickly and efficiently.

In fact, with CompuServe's Internet access, you'll find the Internet as friendly and easy to use as CompuServe itself

This 1995 CompuServe leaflet explained what the Internet would offer with the help of the new Mosaic web browser; the worldwide web was 'coming soon'

In 1994, neophyte America Online users were granted Usenet access in a period since dubbed 'Eternal September' (the time when, traditionally, students suddenly appeared online at the start of the new semester). AOL users, who were often trying the Internet for the first time, would stumble into previously disciplined and tightly-focussed 'professional' Usenet newsgroups. Seasoned regulars resented this uncultured invasion very much, and became annoyed that silly or discourteous questions were being asked by 'newbie' AOL users. I witnessed this myself on Usenet at the time, when I wondered why, from my British viewpoint, so much vitriol was being hurled at anyone having an AOL address (whatever AOL was – I had no idea). Newcomers were scalded for not 'reading the FAQs first' before bothering newsgroup regulars with their questions. Jargon, including RTFM, 'aol lusers' [sic], 'netiquette' and 'trolling' were bandied about as beginners flooded online in their droves. A seminal book of the time, entitled *net.wars* (ISBN 0-8147-3103-1) by Wendy Grossman, an American author living in Britain, laid bare the story of 'The Making of an Underclass: AOL', which also explained how AOL customers were discriminated against by everyone else, just because they used AOL to access the Internet. Already, prejudices were forming as the Internet started to become more 'democratised'. It was said at the time that 'The Internet was cool until everyone discovered it,' and traditional Usenet users mourned the erosion of quality and discipline when everyone clambered on board.

Usenet's great legacy of archived posts was eventually curated by Deja News before being bought by Google. Since then, Usenet has lost its focus and has largely become neglected, although happily it's not been entirely abandoned. You can still experience Usenet at: **https://groups.google.com** or **https://en.usenet.nl/usenet/**

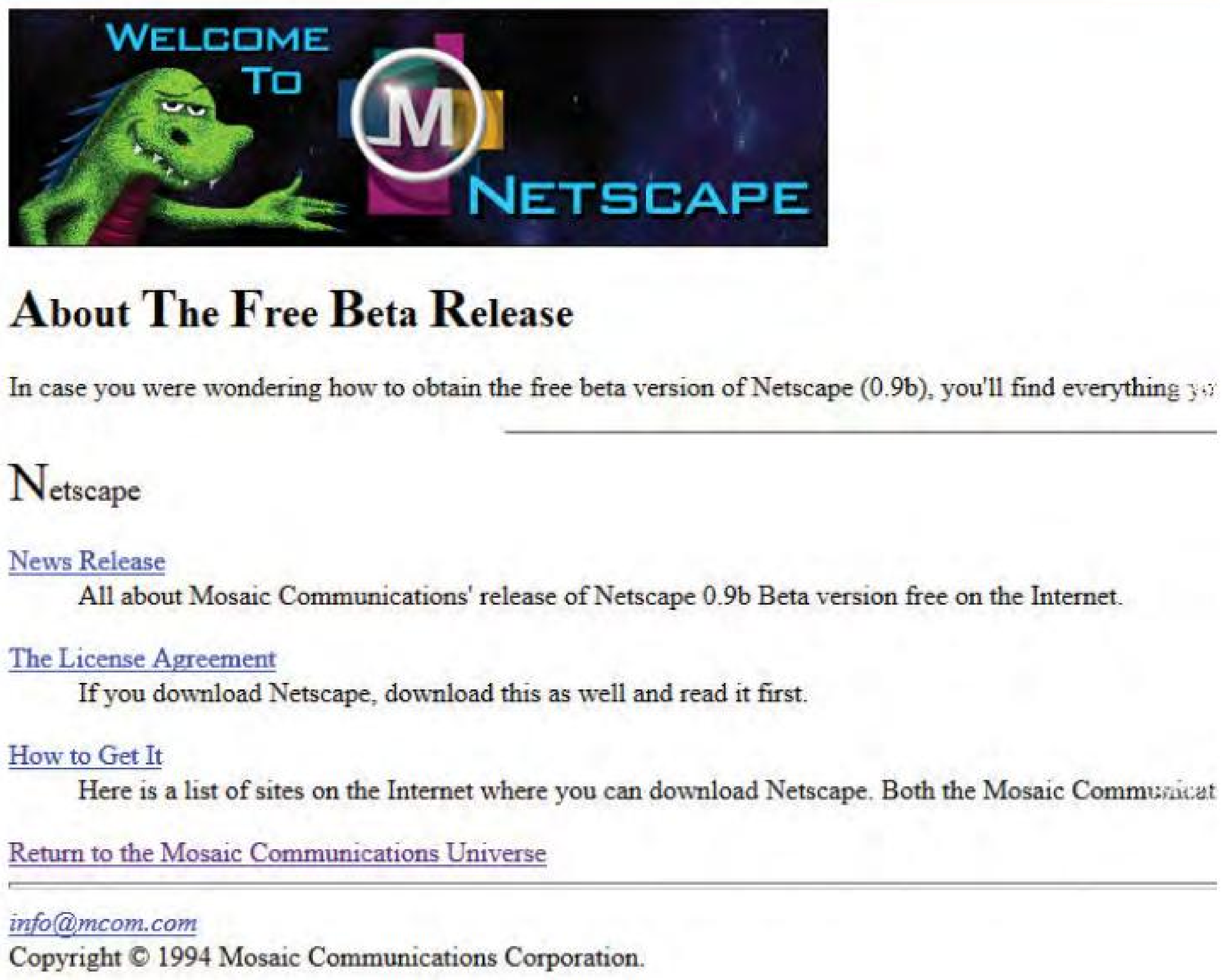
Mozilla roars into life

Compared with CompuServe, email or Usenet, the worldwide web had yet to feature much in everyday life. A novel new program called a 'web browser' was needed to access a rising number of websites dotted around the world, and paperback directories of website addresses helped us to pick and choose from them. NCSA Mosaic was among the first dedicated web browsers (try the simulator at: **http://www.dejavu.org/emulator.htm**), while Microsoft was nowhere to be seen until it launched Internet Explorer 1.0 in the mid 1990s. A shareware rival called Netscape Navigator, devised by ex-college graduate Marc Andreessen and his team, became the mainstream web browser of choice for 75% of users at one time. In Britain, Netscape was distributed by Unipalm Pipex and others, and Netscape even offered a £15 amnesty for unlicensed users of Netscape Navigator 1.0, which 'opened the door to guilt-free web surfing'. Netscape's mascot was a dinosaur nicknamed Mozilla (Mosaic Killer – a portmanteau of NCSA Mosaic and the super-monster Godzilla) which would become familiar to us all, and its legacy lives on today in the Mozilla Foundation that has given us the Firefox web browser. Dave Titus was Netscape's artwork illustrator and he recounts the story of Mozilla at: **http://www.davetitus.com/mozilla/**

The advent of Windows 95 followed by Windows 98 brought more Internet-aware features to computer desktops. Popular programs such as Unmozify allowed users to cache websites offline for future reference, which was often cheaper and quicker than visiting the URL again. Web developers dabbled with 3D virtual reality modelling language (VRML), online whiteboarding and CoolTalk – Netscape Navigator's Internet telephone and conferencing tool. By now, magazine cover CDs offered CompuServe 2000 software, assorted email programs, little Windows dial-up utilities and even SETI – the Search for Extra-Terrestrial Intelligence, which harnessed spare PC power to process radio telescope data using SETI's BOINC program.

Then the infamous AOL CD-ROMs landed on our doormats: millions of them, offering dial-up access and which helped push Internet access into the mainstream market. Suddenly, everyone was getting onto the 'net.

AOL's Instant Messenger (AIM) was a new idea that offered 'buddy lists', a novelty that showed automatically which of your friends were online. Late 1990s Windows programs such as ICQ (I Seek You) from Israel's Mirabilis provided a new way for ordinary Internet users to communicate with each other: now you could invite other ICQ users onto your 'contact list', chat with them 'terminal-style', see user status (online/offline) and handle peer-to-peer file transfers. AOL eventually bought Mirabilis (and Netscape), while Microsoft and Yahoo! offered their own rival messenger programs. Instead of using more regimented email, instant messaging (IM) freed up users and allowed them to keep up effortlessly with their friends.



WELCOME TO NETSCAPE

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Netscape was spun out of work developing the Mosaic browser; their Mozilla dinosaur mascot became familiar to every user – 1994 image

Raw data

London's Demon Internet was among the first in Britain to offer a simple 'raw' Internet service connected through a local 'point of presence'. Data transmission speeds at home were painfully slow and one modem would be replaced by a newer, faster one until dial-up technology reached the maximum speeds possible over creaky phone lines – 56kbps. Not many users could afford to stay online for very long and the idea of 'unmetered access' rapidly found favour. With dial-up access typically costing £10 a month or so, in 1998 Britain's Freeserve ISP totally changed the game: their dial-up access was subscription-free apart from the cost of a local-rate phone call. The idea was a runaway success, unseating AOL's huge customer numbers at a stroke. Other ISPs came and went: LineOne was swallowed by Italy's Tiscali (now TalkTalk), a very efficient ISP that romped all over the European dial-up access market for a time. Search giant Alta Vista (see later) also offered flat-rate access in the UK.

An increasing problem in Britain was the general lack of spare telephone landlines, so in order to cope with the extra demand DACS (Digital Access Carrier System) boxes were installed by BT to share phone lines electronically. This was deeply unpopular with users whose dial-up speeds often halved as a result of the dreaded 'DACSing'. Wealthier users leased a pricey ISDN line before ADSL started to appear, offering always-on access and higher speeds, provided users were not too far away from their local exchange. Tiscali flirted with early trials of satellite Internet access for those who wanted more speed or where location was a problem. Data throughput increased from 500kbps to several Mbps over time as confidence in ADSL technology grew. Wireless networking arrived as well, at last unshackling desktop PCs and laptops from the wall-mounted phone socket.

The upsurge in Internet usage was coupled with an explosion in electronic commerce, with simple shopping cart systems going online in the 1990s. A barely-known online bookseller in Washington state called Amazon Inc opened in 1995, and for a while I enjoyed buying online and importing books from the US before they were released in the UK. CDs and other small items were added onto the range and Amazon arrived in the UK and Germany in 1998. Online auction house Ebay also opened in the mid nineties, allowing anyone to buy and sell merchandise new or old. A hardly-known firm (from my perspective) called PayPal was just one of many processors that American businesses could choose to handle e-Commerce payments, but credit card processing in Britain was difficult during these early years due to the lukewarm interest shown by major banks, who were slow to climb online. Nowadays, e-Commerce trading is a seamless process that has become second nature, but it still springs some surprises – today an item bought online from China arrived on my desk posted from somewhere I admit I'd not heard of before: Vientiane, the capital of Laos (as Wikipedia soon told me).

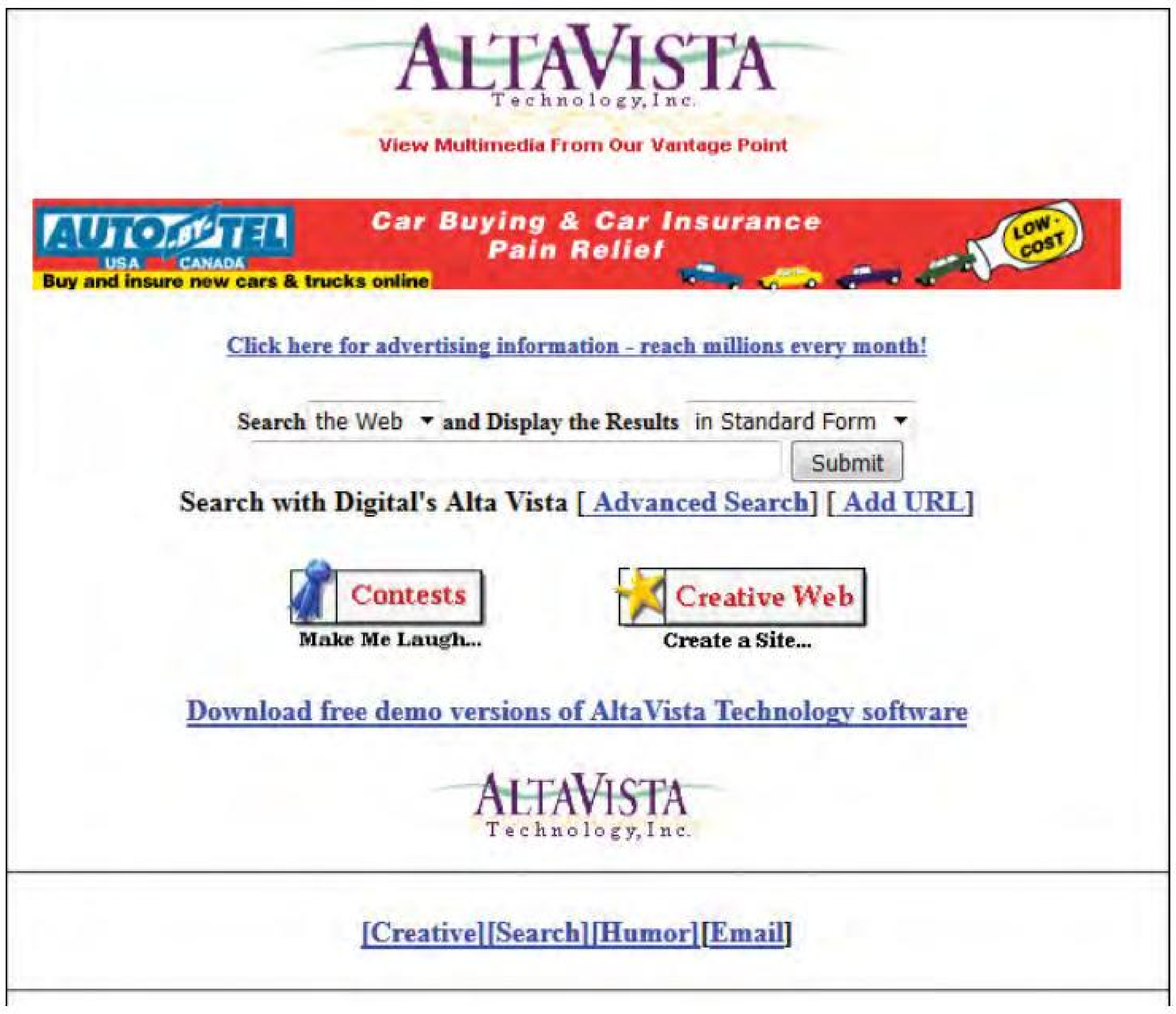
Searching for answers

One major problem for users was knowing where to find online information, and early search engines were soon toying with the need to 'spider' or index the contents of websites and databases. Files were initially hosted and shared on FTP servers and anyone could download them via 'anonymous FTP'. The earliest pre-web search engine (Archie) trawled FTP sites, and the Gopher engine could search text documents. As the worldwide web was very small and manageable then, a 1993 tool called the World Wide Web Wanderer was devised by an undergraduate at MIT to track its growth. It claims to be the first automated web 'spider' (**http://www.mit.edu/~mkgray/net/background.html**).

One of the earliest true search engines was AltaVista, created by Digital Equipment Corp. (DEC, later bought by Compaq and acquired in turn by HP) which was marketed to demonstrate the prowess of DEC computers. America's ARPA sponsored the creation of Inktomi and HotBot search, whose engines would be used to power many popular search sites of that era. Other engines included Lycos, InfoSeek, Yahoo, GoTo and Excite, which was spun out of work by Stanford students at a time when the trendy idea of 'portal' websites was also taking shape. Two Stanford electrical engineering students Jerry Chih-Yuan Yang and David Filo were also working on an idea, this time to build a searchable index or directory of websites and the initial result was *Jerry and David's Guide to the World Wide Web.* This hierarchical hotlist was the forerunner of the Yahoo! Directory, which at one stage could charge websites to be included in its listings. The Yahoo! Directory itself closed in 2014, although Yahoo! had bought the Alta Vista brand many years earlier after the venerable search engine lost ground to Google.

Two young Stanford computer science students, Larry Page and Sergey Brin studied AltaVista very closely and were intensely interested in the subject of data mining. They wanted to apply these techniques to find information more accurately on the growing worldwide web. Page and Brin had worked on an experimental search project, which at one point saw them literally trying to 'download the entire web' onto their computers, so that they could analyse all its hyperlinks offline. In David Vise's book *The Google Story* (ISBN 0-330-44005-5), Larry Page outlined his theory that hyperlinks (to other websites) could be treated like 'citations', and therefore the more hyperlinks to a page there were, the more important the target web page was likely to be. The idea was refined and a newly-named Google search engine was used by Stanford campus staff and students, starting in 1997. So good was Google's accuracy, they felt, that an 'I'm Feeling Lucky' button offered a quick route to the top listing.

Page and Brin then set up shop in a garage to develop the idea further, and today Google is probably the world's most powerful online brand. All of those aforementioned names were instantly recognisable by Internet users of the 1990s, the era when online search was developing and the future direction of the Internet was taking shape. Another new industry, Search Engine Positioning/Optimisation (SEP/SEO) was created as online businesses recognised the value of appearing high up in a search engine's results. Web page designers could, for a time, rig search results but Google soon learned how to outfox them. Google's Page Rank values became important to website owners (Page being named after Larry Page, not web page).



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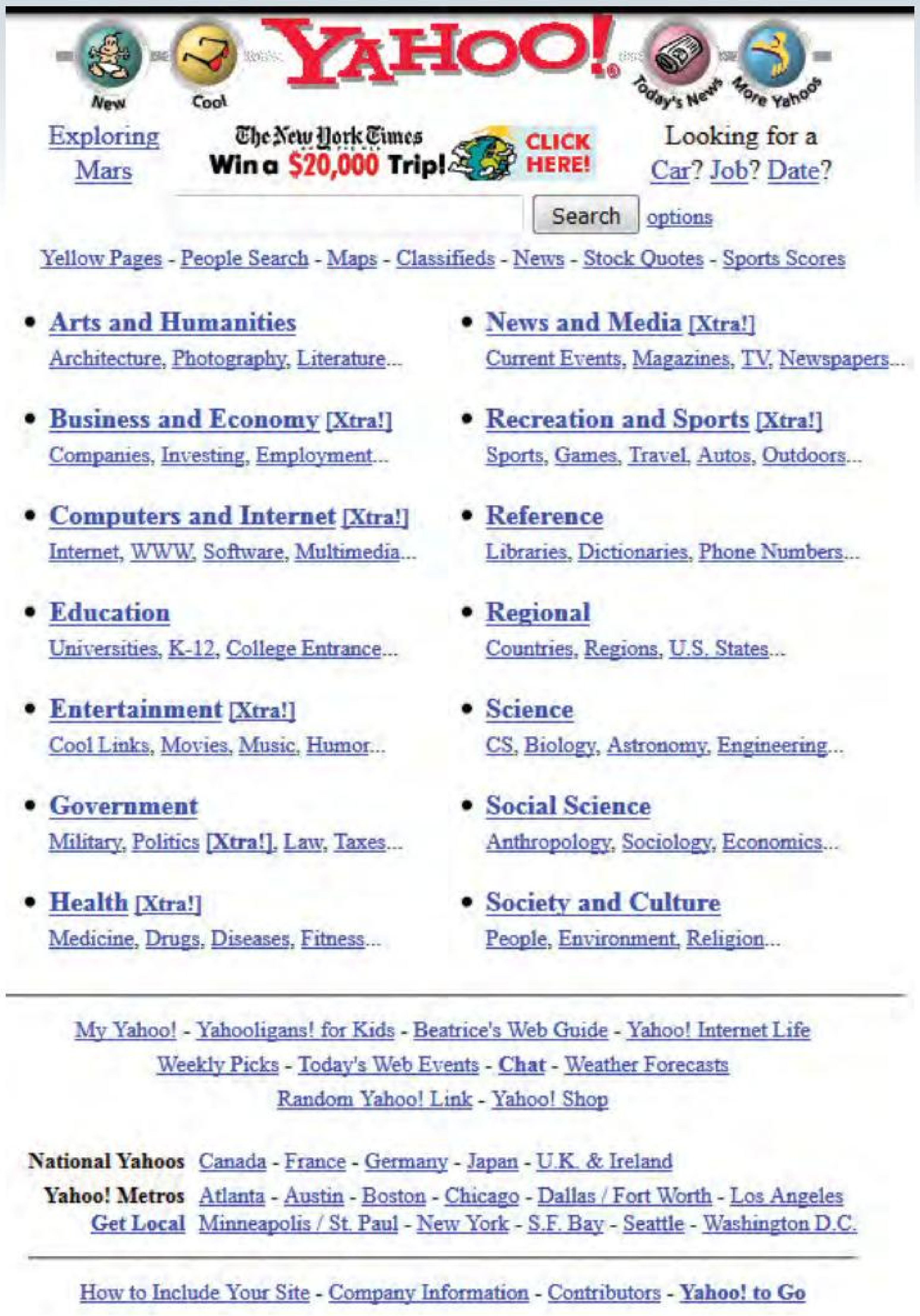
Alta Vista was a new breed of web search engine and its uncluttered design would inspire the founders of Google – early 1996 screenshot



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How to Include Your Site - Company Information - Contributors - **Yahoo! to Go**

A 1997 screenshot of Yahoo! which was a maintained directory of websites; companies would eventually pay to be featured. It closed in 2014

Let's get together

The next trend coming around the corner was 'social networking'. Thanks to a greater availability of Internet access and better software, enthusiasts could now build their own web pages and hoards of 'static' websites showing photos of holidays, kids and family pets suddenly appeared online. The need to understand HTML and FTP inevitably deterred ordinary, non-technical users who simply wanted to broadcast themselves online. As design techniques improved, the so-called 'Web 2.0' emerged, along with social media, the idea being that anyone could publish content online easily and rapidly. The first web logs – 'blogs' – appeared, with opinionated 'bloggers' carving names and reputations for themselves online. Along came the idea of podcasting, initially audio streams such as shows, music, opinion pieces or interviews that could be downloaded onto a portable player for listening offline. Radio listeners were soon urged to 'download the latest podcasts' from some commentator or other.

In the mid 2000s, YouTube sprang up as an independent video-sharing site – no need to struggle with hosting your own video clips any more – before being snapped up by Google, who monetised it with adverts. Facebook would become the dominant force in social media, allowing anyone to share material online and categorise those who could view it. This would raise all manner of privacy questions and the new phenomenon of 'over-sharing' emerged: earnest users were eager to tell their story to anyone who would listen, if only they could configure some 50+ privacy settings properly!

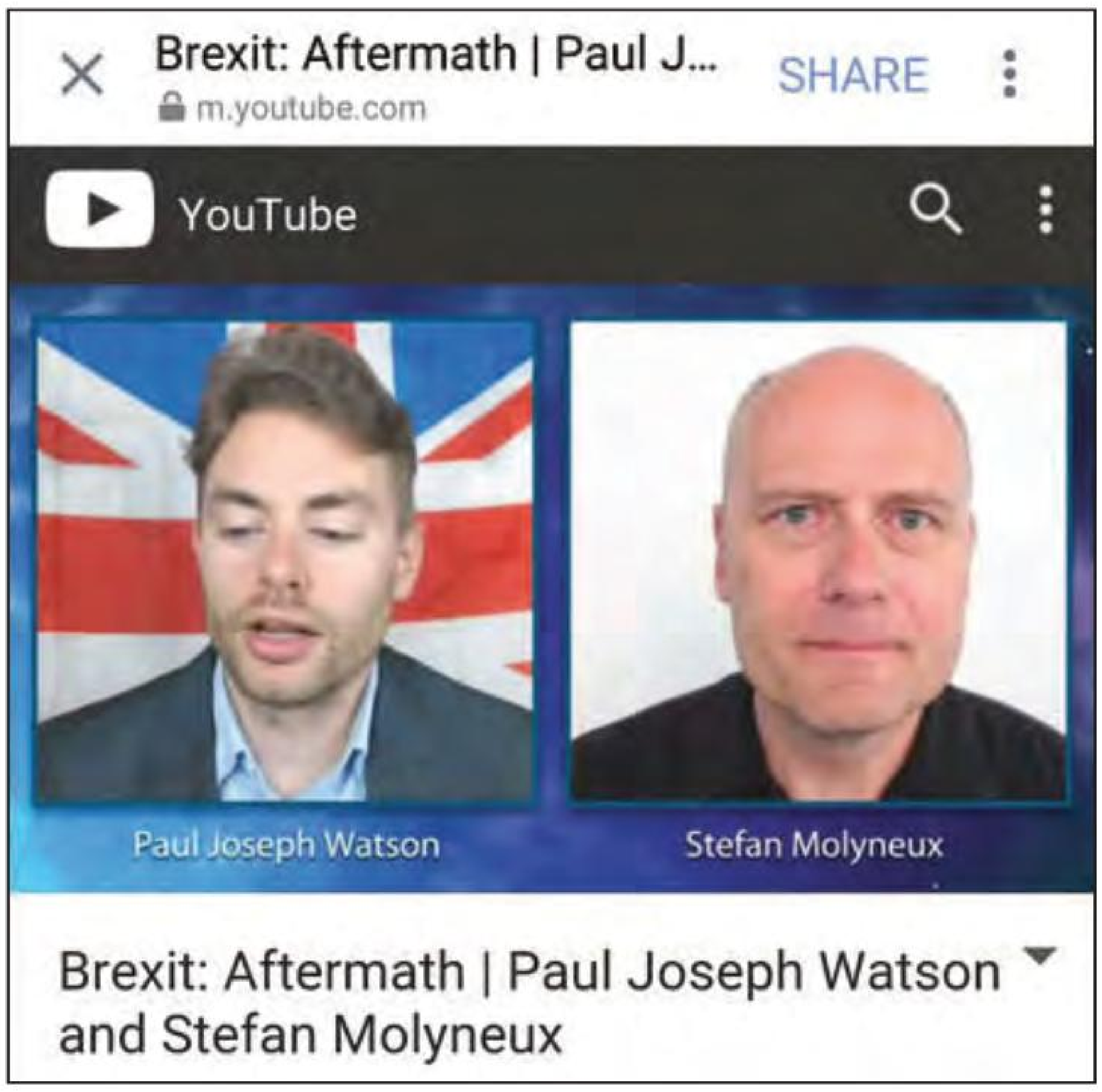
All of a Twitter

Offering an even easier, always-on way of expressing oneself to like-minded followers, Twitter gripped users with its rapid-fire 140 character 'tweets' that gave voice to the 'twitterati' – everyone from footballers to pundits to politicians. Hashtags (simply Twitter meta keywords) entered everyday language, allowing users to track a particular trend on Twitter, re-tweeting 'tweets' and garnering opinions effortlessly. In effect, Facebook and Twitter became the go-to social networks to share, comment, debate or fire off abuse about everything under the sun. You can publically embarrass your mobile phone provider on their Facebook page or on Twitter, and the desire to 'go public' this way and shrug off one's own privacy has been a curious side-effect of the Internet's popularity among today's generation.

Developments accelerated with the growth of smartphones and tablets. Wi-Fi connections at home or on the move allow users to keep abreast of the latest news, email and social messages. TV and radio offer us streaming or catch-up programmes, and the advent of cloud computing has created online resources and storage that is 'out there somewhere' – though nobody really seems to care where.

More recent history has seen the introduction of fibre to the cabinet (FTTC), delivering much higher speeds to the home, perhaps 45Mbps or more, a thousand times faster than ARPANET's earliest leased line networks. The Internet of Things (IoT) promises to network common appliances and allow remote control from a smartphone app, and there is much apprehension about the possible security risks from hackers and talk of 'virtual wars', with opposing nations slugging it out electronically.

Today, tweets are a cheap way of filling column inches in news reports and TV screens, and a perfect example of the power of social media was that of Britain's historical Brexit Vote held on 23 June 2016, a date for the history books. The web, Twitter, Facebook and YouTube all played prominent roles in shaping opinions across the UK and further afield, allowing the voice of ordinary people to be heard and shared on equal terms. The Internet – the Interconnected Network of Networks – is today a vital utility that bears no resemblance to the faltering steps of the world's first packet-switching project constructed nearly half a century ago when the world was a very different place. Our own 'Generation Z', which has never known life without the Internet, has been gifted with immense power placed at its fingertips, all stemming from the very first 'Login' command typed into a machine in UCLA back in October 1969.



Brexit: Aftermath | Paul J...

m.youtube.com

Brexit: Aftermath | Paul Joseph Watson and Stefan Molyneux

All of a twitter: social media in action after Britain's EU-Exit Referendum in June 2016 (Stefan Molyneux video blog on Youtube).

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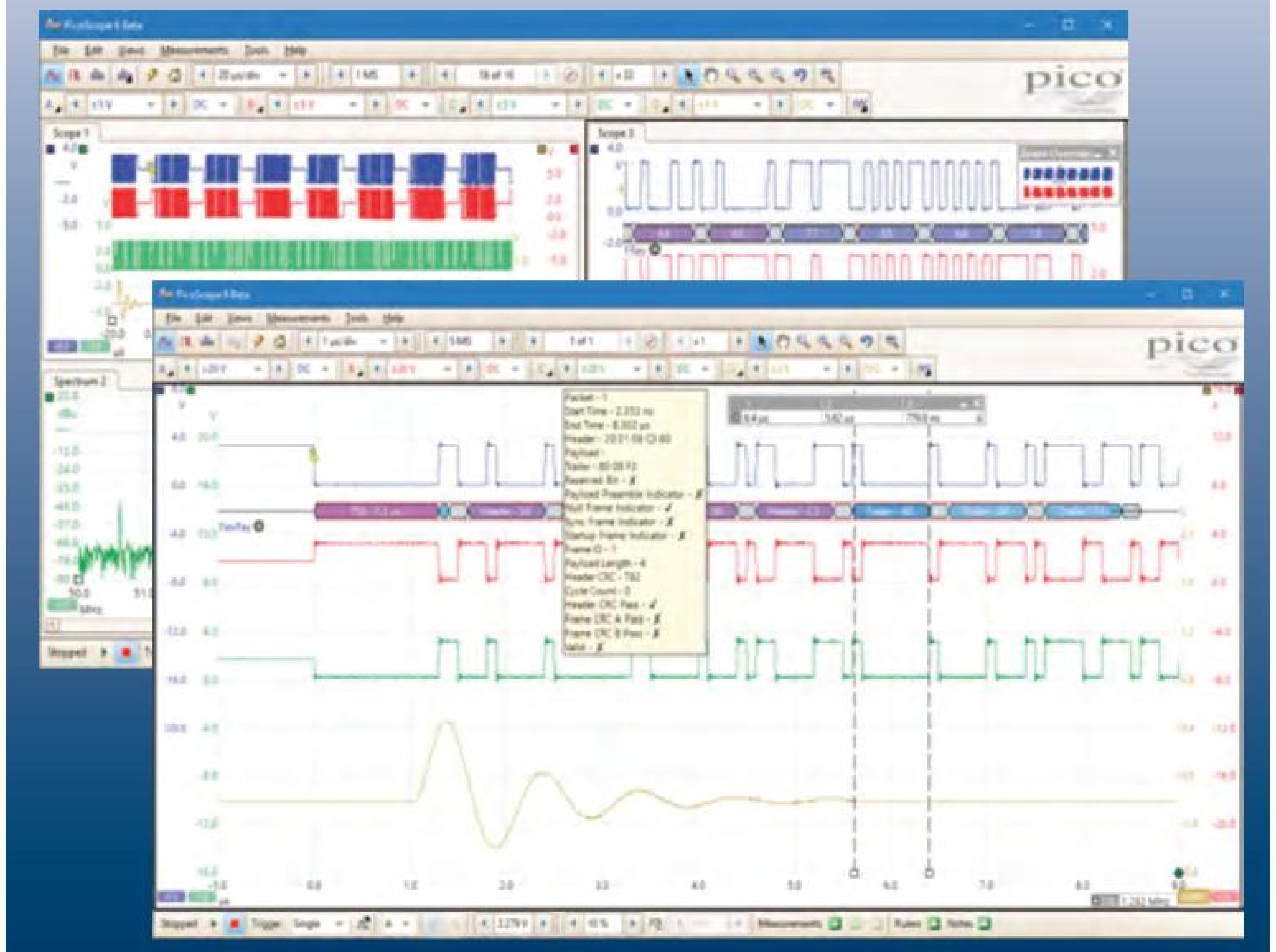

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BY IAN BELL

AC bias and MLCCs

FREQUENT *EPE Chat Zone* contributor ***741*** poses a question: ‘I sometimes see the phrase “ac bias”. Other than in the context of magnetic recording – what can this mean? 1V dc + 0.5V ac is an ac signal with a dc bias... Surely it’s never described as “a dc signal with ac bias?”’ In a later post, ***741*** noted that an example of the use of the phrase was in an article in *Power Electronics Technology* titled ‘Capacitor Values: Don’t Believe the Label’, quoting the statement: ‘Parameters such as aging, frequency and ac bias … are also often overlooked, …’ (For full details of the source see reference [1].)

The term ‘bias’ has a general meaning in everyday usage, where the dictionary definition is something like ‘predisposition or prejudice’, and has different meanings in various special contexts, including electronics, statistics, fabrics and the sport of bowls. In general usage, the word usually has negative connotations, but this is not the case in an electronic context, where quick definitions of bias are usually along the lines of: ‘a steady voltage applied to a system or device’. This is a somewhat rough-and-ready definition – for example, bias can be applied current, and ‘steady’ may give the impression of dc; however, a fixed frequency and amplitude ac signal is also a steady condition.

Biased electronics

Perhaps the best-known use of the term ‘bias’ in electronics is in the context of transistor amplifiers and similar circuits. In these situations the bias is strictly dc, hence ***741’s*** surprise at the use of the term ‘ac bias’. The word ‘bias’ means something different to a statistician, dressmaker and bowls player and it can mean different things in different contexts within electronics. A power electronics engineer discussing the minutiae of capacitor performance does not need to justify accepted terminology in articles aimed at other specialists, which may make them difficult to read for an outsider. However, the difference in meanings of bias within electronics is not that large and is generally covered by ‘a steady voltage applied to a system or device’ (with the caveats noted above).

Bias in electronics commonly refers to the voltages or currents being applied to a component or circuit in normal, default or no-signal conditions. These conditions are often referred to as the operating point of the component. For example, for a transistor, the bias may set up a particular emitter current which will determine the gain and input resistance of the transistor. In effect, the bias ‘programmes’ the transistor to have particular characteristics within the range covered by the device. Biasing amplifiers and similar circuits also concerns setting up the no-signal dc conditions in the circuit as whole, so that the node of interest with no signal is at the correct level, and/or so that there is sufficient ‘room’ available for signal changes. For example, a node in a circuit with a 5V supply may be biased to 2.5V with no signal so that a maximum symmetrical change of ±2.5V is available for the signal.

Bias can also mean the voltages or currents being applied under which some measurements of component parameters are made; this may be in the context of component characterisation or sensing. The first of these is the context in which ac bias is use in the paper mentioned by ***741***, which concerns the variation of capacitance of capacitors under different conditions. During each measurement a steady dc and ac voltage is applied, similar conditions may then apply when the component is used in a circuit.

Sensors may need to have either or both dc and ac bias applied to set their required operating conditions. A sensor based on a capacitance that varies with the sensed value would typically have a fixed ac bias applied to it. The sensed value is then obtained by variations in the sensor current, or the voltage difference in a bridge circuit. Choice of the correct ac bias voltage and frequency may be important in getting the best performance from such a sensor, but once set up it is ‘a steady voltage applied to a system or device’.

Non-ideal components

Having provided a general idea of what ac bias might mean beyond magnetic recording it is interesting to look in more detail at the issue behind the paper which caused ***741*** to come across the term. This concerns the detailed characteristics of real capacitors, specifically multilayer ceramic capacitors (MLCC), which is important because their non-ideal behaviour may have a significant effect on circuit performance.

We will look at the reason why ac bias is of interest here later, but we will start by discussing the impact of non-ideal component characteristics in general and then look at the basics of capacitors and dielectrics. The right choice of capacitor dielectric is often important in getting a circuit to work properly. It can be difficult for those new to electronics who are faced with a huge array of choices when looking for capacitors on suppliers’ website. The fact that they may be distinguished by cryptic-seeming codes such as ‘X7R’ does not help.

In basic electronics design we make simple assumptions about components. For example, we might work out that a 10nF capacitor is required. What else might we need to know? Possibly it’s maximum working voltage or its precision (if the circuit needs accurate component values). We also have to decide on the packaging (for example, axial lead or SMD) if we are actually going to build the circuit. However, when making these decisions there is probably an underlying assumption that a capacitor is simply… a capacitor. It has a fixed capacitance (plus or minus the precision percentage), and that’s it.

Parasitics

Unfortunately, real components do not simply have an unvarying value. Their value may change with a range conditions, including temperature, applied dc voltage, applied ac voltage and applied ac frequency. Component values also change with time as the component ages. Furthermore, for the three basic passive components – resistors, capacitors and inductors – all have three properties to some extent. For example, any real resistor will have some capacitance and some inductance; it will not really be a pure resistor. These unwanted additional properties are called ‘parasitics’ in general, or named specifically – for example, ‘parasitic capacitance’.

We looked at this issue in some depth in the context of SMD ferrite beads (which are a type of inductor) in the February 2016 edition of *Circuit Surgery*, discussing the change of inductance with frequency and associated parasitics.

It is possible to build many interesting and useful circuits without worrying too much about non-ideal passive component characteristics, but you cannot assume that you will always be immune from them. One example, which is probably quite commonly encountered, is the output capacitors on low drop out (LDO) voltage regulators, which may be required to have a certain resistance (equivalent series resistance – ESR). Datasheets for LDO regulator ICs are very specific about what type of capacitor to use. If the ESR value is not within a given range (either too high or too low) the feedback loop of the regulator may become unstable and the device will not function correctly.

Changes

For someone experimenting and designing a one-off circuit, non-ideal component behaviour may not be too much of a problem. If one component does not work as hoped it may be straightforward to try others until the circuit is OK. However, commercial designers have to worry about a design delivering working circuits in production, under all expected usage conditions, subject to component variability and non-idealities. Therefore, it is necessary to take many non-ideal characteristics into account when designing and simulating circuits, particularly in demanding applications, or situations where worst-case analysis is required because of the critical nature of the application.

Commercial designers need to consider the supply chain – if a capacitor manufacturer X stops being able to supply a component and we swap to manufacture Y, will the circuit still work? If the circuit is designed to use a capacitor of a certain value and tolerance, and occupy a certain volume of space on the board, then a different device of the same type, value and tolerance, with the same footprint and equal or smaller volume should be fine. However, if the performance of the circuit is affected by non-ideal characteristics, and these are different between the two manufacturers, then problems may arise. The relevant information *may* be available in a datasheet, but checking suitability may not be straightforward.

Another issue in commercial design may be simulation accuracy. If simulation is used in the design process then there is a concern about how accurate the models of components are, particularly if non-ideal component characteristics have a potentially strong impact on circuit performance. However, the availability of free analogue simulators, such as LTSpice, means that anyone, not just professionals in large companies, may ask the question: 'is this model good enough?' The previously mentioned *Circuit Surgery* article on ferrite beads was prompted by a *Chat Zone* question on simulation models.

The paper [1] ***741*** mentioned concerns the use of ceramic capacitors in power-supply applications. It is motivated by the need for understanding and modelling the consequences of non-ideal component characteristics as designers push to achieve higher performance circuits, which are subsequently more sensitive to non-ideal characteristics and hence more difficult to model. Before looking at some data on the effect of dc and ac bias on ceramic capacitors we will look in general at capacitors and their dielectrics, to help cover the concepts behind this aspect of the paper.

Capacitor basics

A capacitor comprises two conductors separated by a non-conductive region called the dielectric. The simplest capacitor structure is two equal parallel plates of area *A* separated by a distance *d* (the thickness of the dielectric) – see Fig.1. The capacitance, *C*, of the parallel plate capacitor depends on the dimensions (*A* and *d*) and the response of the dielectric to the presence of an electric field. Increasing *A* or decreasing *d*, increases the capacitance, so the capacitance is proportional to *A*/*d*. The property of a (dielectric) material in response to a electric field is called permittivity.

In a vacuum, that is with no dielectric material present, the constant of proportionality between *C* and *A*/*d* is the permittivity of free space, also called the electric constant, $\varepsilon_0 = 8.85418782 \times 10^{-12}$ F/m (farads per metre). The symbol ε_0 is the Greek letter lower-case epsilon, which is used for permittivity in general, with the subscript zero indicating the vacuum permittivity.

With a dielectric material present we can use its absolute permittivity ε or its permittivity relative to ε_0, expressed as $\kappa\varepsilon_0$, where κ is called the 'dielectric constant' of the material ($\varepsilon = \kappa\varepsilon_0$). The symbol for dielectric constant is the Greek letter lower-case kappa, but ordinary 'k' is also used in some contexts. A possible source of confusion here is that absolute permittivity can also be expressed using relative permittivity, ε_r, which is the same thing as dielectric constant, but with a different name and symbol ($\varepsilon = \varepsilon_r\varepsilon_0$). Furthermore, there is also potential ambiguity in that the term 'dielectric constant' has been used for ε rather than κ (or ε_r) in some places.

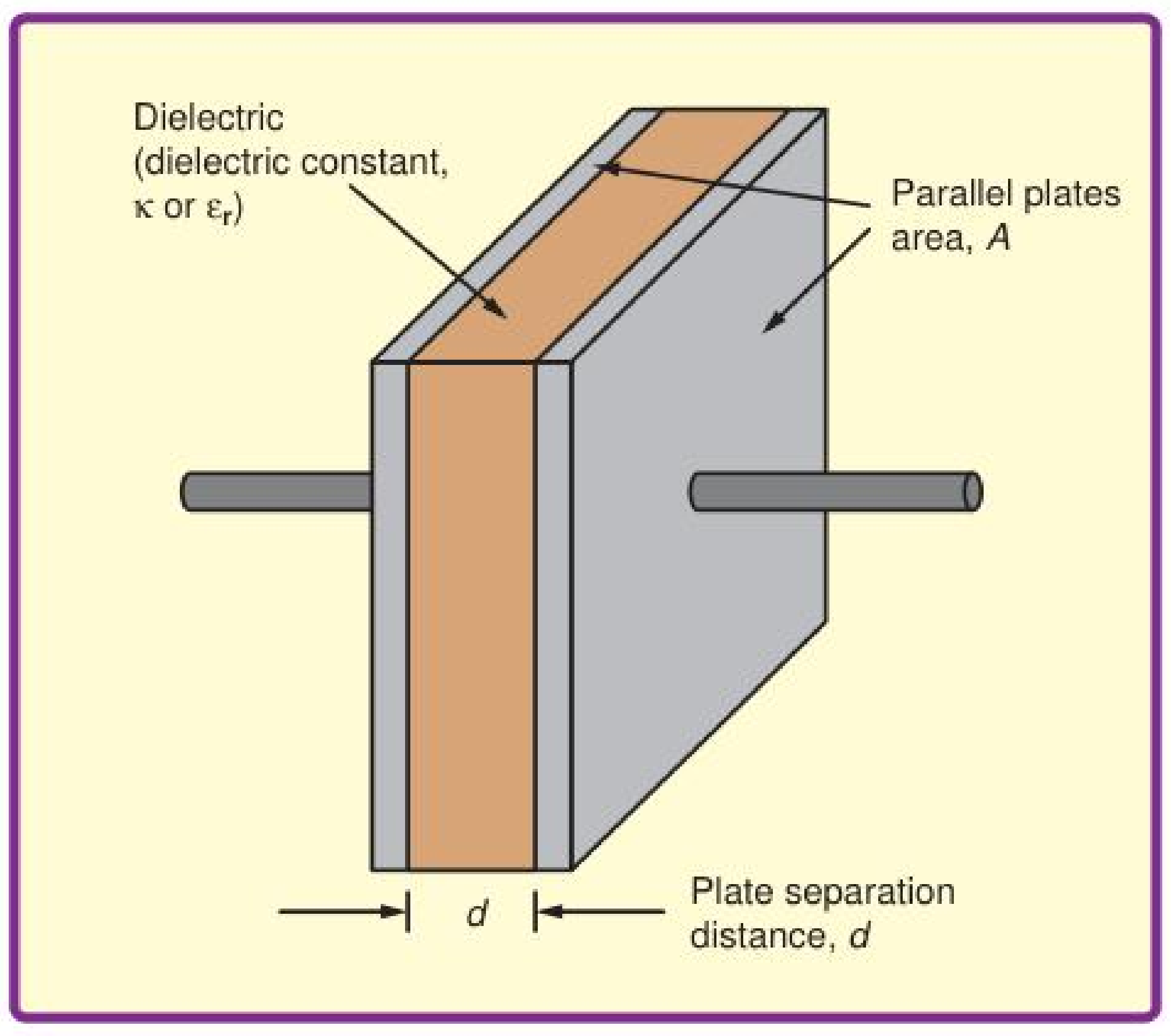
Dielectric (dielectric constant, κ or ε_r)
Parallel plates area, A
d
Plate separation distance, d

Fig.1. Parallel plate capacitor

The value of κ is 1 for a vacuum, by definition, and greater than one for all materials. Values of κ in 10s or 100s of thousands are possible with certain ceramics and polymers. As capacitance is proportional to κ, materials with high κ value are of potential use in capacitor manufacture.

The capacitance of a parallel plate capacitor is given by:

$$C = \frac{\kappa\varepsilon_0 A}{d} = \frac{\varepsilon_r\varepsilon_0 A}{d} = \frac{\varepsilon A}{d}$$

If a parallel plate capacitor has a voltage *V* across its plates then the electric field strength (*E*) in the region between the plates is given by: $E = V/d$ (in volts per meter). Field strength is important when considering dielectrics because permittivity is determined by the effect a material has on field strength. If we have a capacitor in isolation (not connected to a circuit) and it has some charge *Q* on it then the voltage across it will be given by: $V = Q/C$. This is a form of the defining equation for an ideal capacitor. Note that since the capacitor is in isolation then the voltage is determined by the charge and capacitance, it is not applied by a circuit.

Field strength and polarisation

If we have an isolated parallel plate capacitor we can substitute *C* from the equation above in $V = Q/C$ and then divide through by *d* to get:

$$E = \frac{V}{d} = \frac{QA}{\varepsilon A}$$

Given that our isolated capacitor has fixed *Q* and fixed size (*A* and *d*) the equation above shows that if we change the dielectric material the field strength will be smaller the larger the material's permittivity. Materials reduce field strength by becoming polarised – in simple terms polar molecules within the dialectic will change their orientation from their normal random state to align in the opposite direction to the applied field, reducing the total field strength. This is fundamentally what permittivity is about – the way the material polarises in an electric field.

Electric field strength is also important in terms of the maximum working voltage of a capacitor. Dielectric materials have a maximum electric field that they can withstand (under ideal conditions) without breaking down, which is called the dielectric strength. In practice, breakdown will tend to occur at lower field strengths due to factors such as imperfections in the material. From the definition of field strength it can be seen that reducing *d* for a capacitor will decrease the voltage required to obtain a given field strength. Thus capacitors with thinner dielectrics will have lower maximum voltages.

The polarisation of dielectric materials is a complex process that can occur via a number of mechanisms. As might be expected, at least for some materials, the mechanism and hence the permittivity may be strongly dependent on temperature. Also, the amount of polarisation is not always proportional to the applied field (it is nonlinear), and may exhibit hysteresis. This means that permittivity can change with the voltage applied to a capacitor, so the capacitance of a capacitor may depend on the applied voltage.

Furthermore, polarisation (movement of molecules etc) does not occur instantaneously, so the response of the material will depend on the rate of change of an applied field (can the polarisation occur fast enough to keep up with field changes). This means that permittivity depends on the frequency of an alternating applied field and hence the capacitance of a capacitor may depend on the applied frequency. The dependence of the permittivity of a dielectric material on the frequency of an applied electric field is called dielectric dispersion. It follows also that the amplitude of an applied ac signal may also affect the capacitance. This is where ac bias becomes relevant in terms of capacitor characteristics.

MLCCs

These properties of dielectrics result in non-ideal capacitors, returning us to the topic of ceramic capacitors mentioned above. Issues with non-ideal characteristics have become more complex with the trend towards smaller surface-mount device (SMD) components. Variation in capacitance with applied voltage is of particular concern in 'mid-dielectric' and 'high-dielectric' MLCCs, usually packaged as SMD chip capacitors. The term 'high-k' is also used here, with 'k' standing for dielectric constant.

The capacitance of a capacitor of a given size and shape can be increased by using dielectric materials with higher dialectic constants – hence terms such as 'high-dielectric'. These MLCCs use ferroelectric materials, which provide a high dielectric constant but in exchange for other less desirable electrical characteristics, such as variation of capacitance with temperature and voltage.

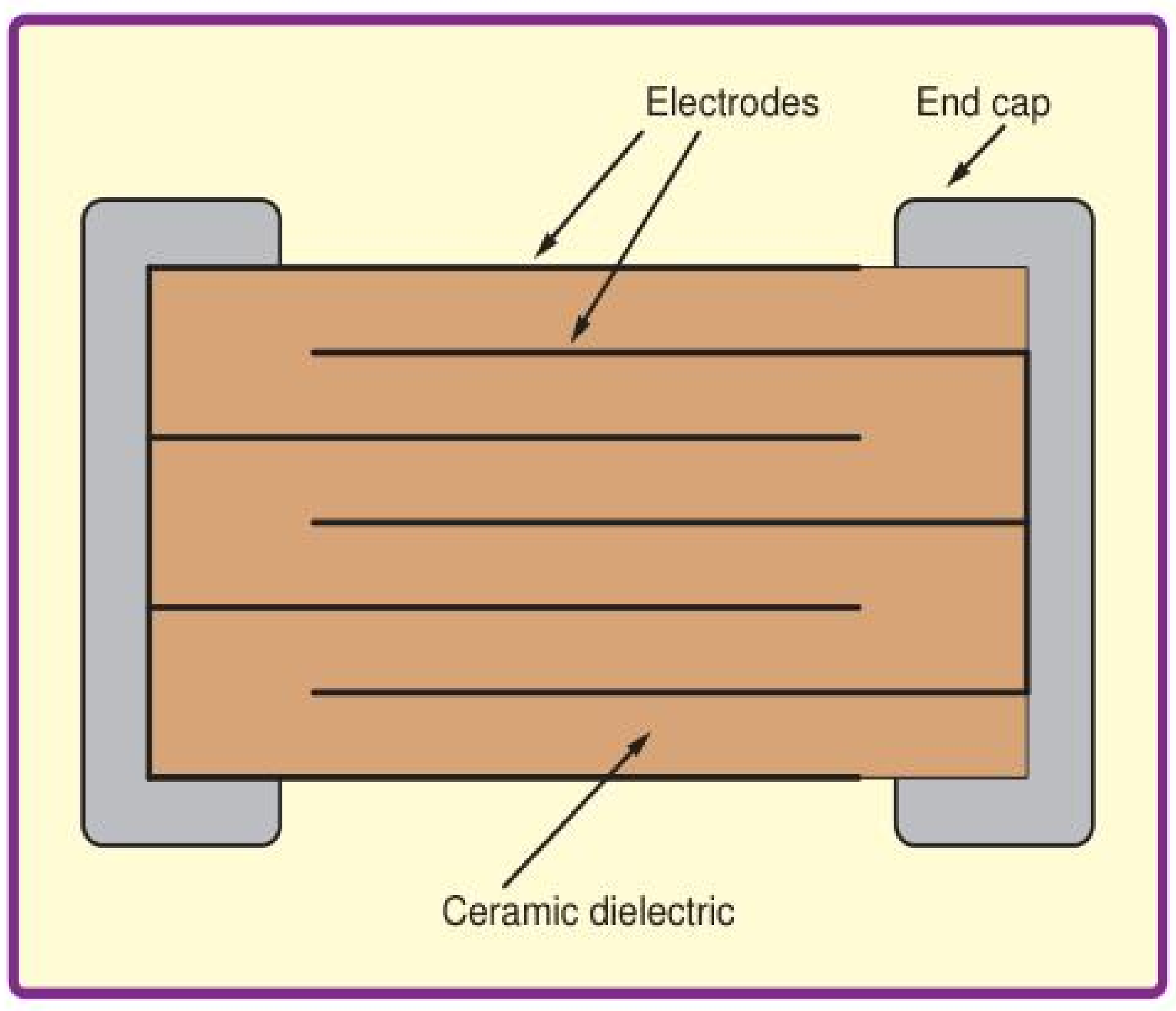

Fig.2. – MLCC chip capacitor structure

Another way to achieve higher capacitance without increasing device size is to reduce the thickness of the dielectric layers (*d* in the equation above). This allows more layers of capacitor plates to be included in the MLCC device. See Fig.2 for a typical MLCC structure. Both the decrease in dielectric thickness, and increase in plate area (in a given volume) facilitated by this, increase the capacitance. However, the decrease in thickness increases the electric field strength in the dielectric (voltage across the capacitor divided by distance between plates, measured in volts per meter). This means that the capacitors are more likely to be operating close to their maximum rated voltage, which is where they tend to exhibit the greatest variation in capacitance with applied voltage.

Classification

The size versus variability trade-off based on choice of ceramic dielectric is covered by an international standard classification system for ceramic capacitors, which indicates their application. Class I ceramic capacitors are larger in size for a given capacitance but have high stability and low losses and are most suited to resonant circuits and timing-critical applications where significant changes in capacitor value cannot be tolerated. Class II ceramic capacitors are smaller but have greater variability. They are suitable for smoothing, by-pass, and coupling and decoupling applications. Here, typically, there is a minimum capacitance requirement, but the specific value is less critical. The 'high-dielectric' MLCCs are of course in class II.

Ceramic capacitors are further classified by dielectric codes. There is more than one system, but the EIA 198 standard is well known and gives us the commonly seen dialectic codes such as X7R and Y5V. The first letter indicates the minimum temperature, the number indicates the maximum temperature and the second letter indicates the change in capacitance with temperature.

Capacitor bias

As mentioned when discussing permittivity the capacitance of a capacitor may depend on the applied dc voltage, ac voltage and frequency. In such circuits, the basic operating conditions experienced by the capacitor can be described as the ac and dc bias, just as the operating point of a transistor can be described as its bias. The difference is perhaps that often the choice of a transistor operating point will be the starting point for setting component values, whereas a capacitor's operating point may depend on the design of the circuit, such as a power supply in which it is used. The question is, under the operating conditions present in a given circuit, what will the actual capacitance be?

The change of capacitance with dc and ac bias may not be the same for different dielectrics and may even be different for nominally the same capacitor (value and dielectric code) from different manufacturers. A detailed investigation of this was published by Istvan Novak *et al* of Oracle-America Inc. at DesignCon 2011 [2] – they measured the effect of ac and dc bias on a variety of ceramic capacitors from different manufacturers. Fig.3 is based on some of their data and shows the variation of capacitance of a 1µF 0603-size 16V X5R capacitor with both dc and ac bias.

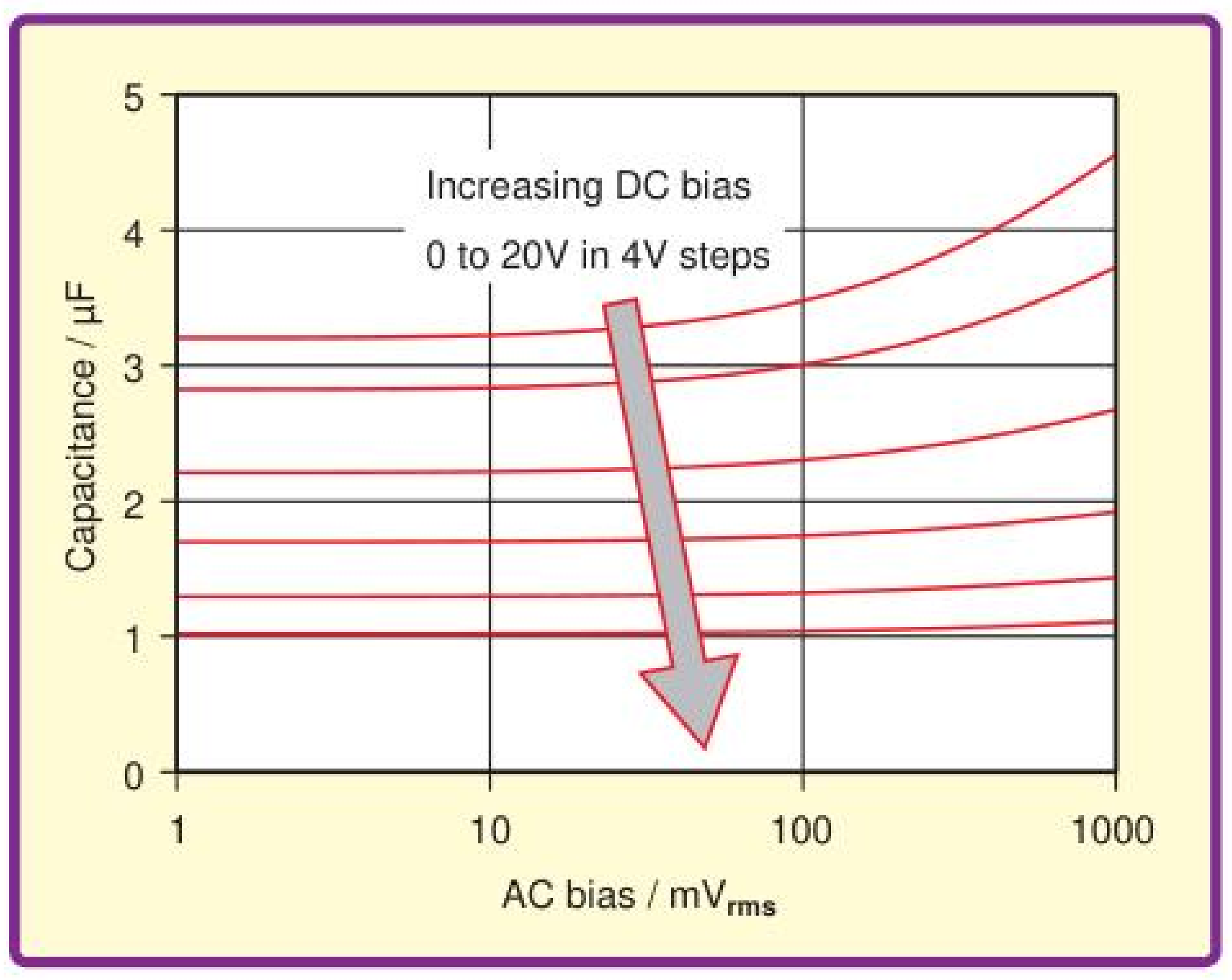

Fig.3. the variation of capacitance of a 1µF 0603-size 16V X5R capacitor with both dc and ac bias. Based on data from Novak et al [2]

Fig.3 demonstrates how the characteristics of a component depend on the dc or ac operating point or bias conditions that it might experience in a circuit. For capacitors in circuits such as power supplies this may be an important consideration during the design, just as setting the dc bias of a transistor is critical. Thus, the answer to ***741's*** question of what is ac bias is quite straightforward, but the implications for designers may be far less so.

References

[1] Sandler SM, Hymowitz CE. Capacitor Values: Don't Believe the Label, *Power Electronics Technology*, May 2007: 22-27.

[2] Novak I, Williams KB, Miller JR, Blando G, Shannon N. DC and ac bias dependence of capacitors, *DesignCon 2011*, February 2011.

Development Tool of the Month!

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PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

PICs and the PICkit 3: A beginner's guide – Part 4

THIS MONTH we reach Part 4 of our beginner's guide. We finally got 'hands on' last month with our first lesson from the *PICkit 3 Starter Kit User's Guide*. This month, we're going to take a deeper look at the code we wrote last month and explain in more detail what's happening. Then we will move on to the next lesson, where instead of turning on the LED, we'll make it blink (Lesson 2). These may seem like very modest aims, but they will provide a solid foundation on which to build more ambitious control using a PIC.

You will gain a greater insight into PICs and what we're trying to achieve if you read the previous articles in this series. You will also need the following software and hardware:

1. Purchase the PICkit 3 Low Pin Count Demo Board (**http://tinyurl.com/h2jj2ek**)
2. Purchase the PICkit 3 Programmer + USB Cable (**http://tinyurl.com/zcpx3le**)
3. Download *PICkit 3 Starter Kit User's Guide* (**http://tinyurl.com/jyqfeuk**)
4. Download MPLAB X IDE (**http://tinyurl.com/hmehqja**)
5. Download XC8 Compiler (**http://tinyurl.com/h5g9k5l**)

Commenting

Before we dive into code, first a comment about 'comments'. In general, when writing a piece of code, it can sometimes be hard to remember what each line does or what you were attempting to do. Adding comments to code is a great way of including human-friendly notes that will be ignored by the compiler at build time, but which can help you long after you've written the code. There are two methods of commenting on code. The first is prefixing a line with two forward slashes, as follows:

```
// This line will be ignored by the compiler
at run time
```

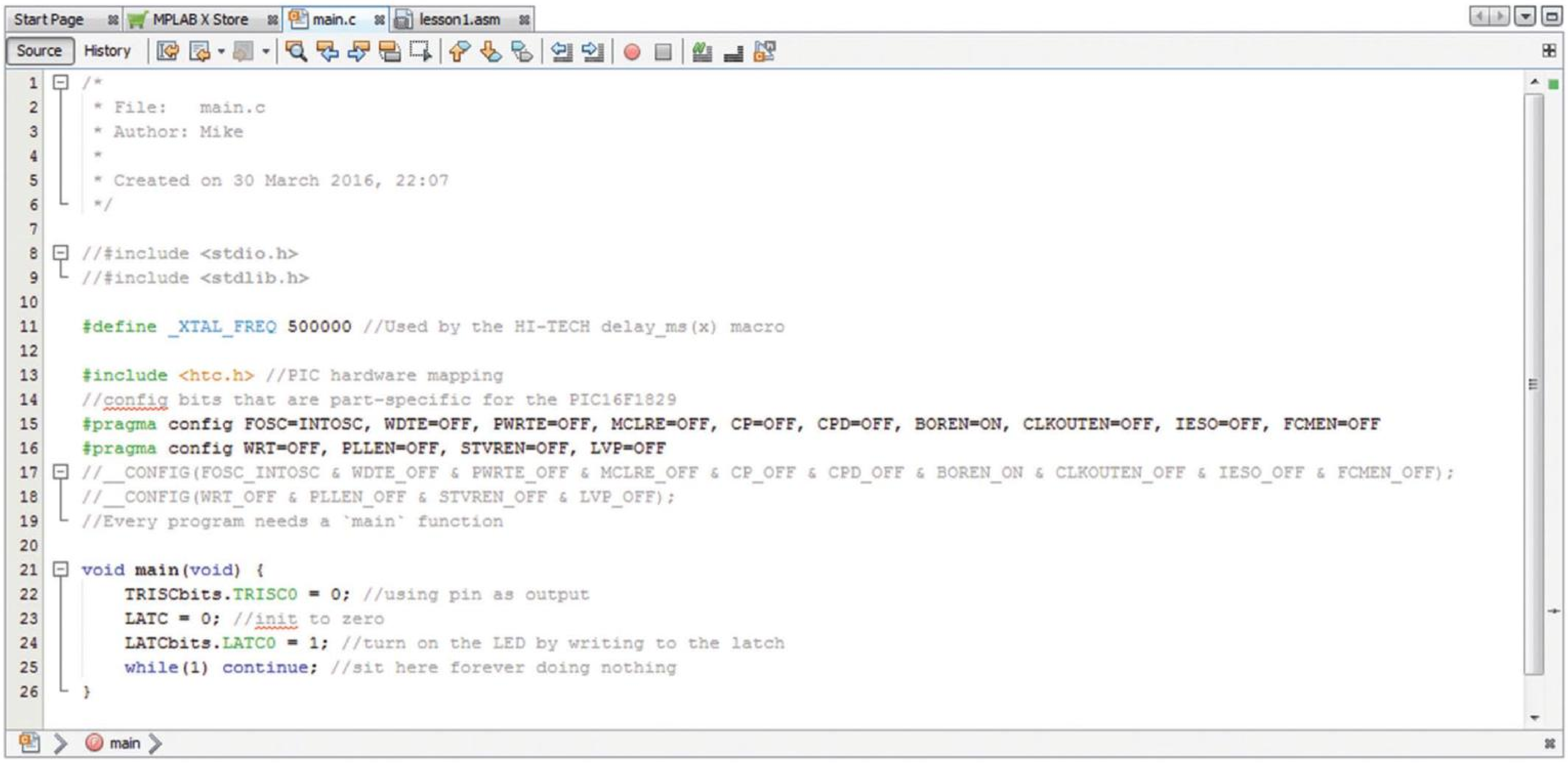
This forces the compiler to ignore everything to the right of the forward slashes. Alternatively, we can easily comment on a whole section with a forward slash and an asterisk at the start of the section, and then an asterisk followed by a forward slash to close it off.

```
/* Everything in the following lines will be
ignored, no matter what is written in them.
if (x == 0) {
      y++;
}
This is the end of the commented section */
```

Breakdown of code in Lesson 1

Last month, we built, compiled and programmed our first piece of code, as shown in Fig.1. (Note that I've added in the corrected `#pragma` directive we discussed last month, and for the sake of completeness I've also left the old `__CONFIG` line in, but turned it into a comment with `//` so it doesn't form an active part of the program.)

In every program we write, we need to include some basic blocks:



```
/*
 * File:   main.c
 * Author: Mike
 *
 * Created on 30 March 2016, 22:07
 */

//#include <stdio.h>
//#include <stdlib.h>

#define _XTAL_FREQ 500000 //Used by the HI-TECH delay_ms(x) macro

#include <htc.h> //PIC hardware mapping
//config bits that are part-specific for the PIC16F1829
#pragma config FOSC=INTOSC, WDTE=OFF, PWRTE=OFF, MCLRE=OFF, CP=OFF, CPD=OFF, BOREN=ON, CLKOUTEN=OFF, IESO=OFF, FCMEN=OFF
#pragma config WRT=OFF, PLLEN=OFF, STVREN=OFF, LVP=OFF
//__CONFIG(FOSC_INTOSC & WDTE_OFF & PWRTE_OFF & MCLRE_OFF & CP_OFF & CPD_OFF & BOREN_ON & CLKOUTEN_OFF & IESO_OFF & FCMEN_OFF);
//__CONFIG(WRT_OFF & PLLEN_OFF & STVREN_OFF & LVP_OFF);
//Every program needs a `main` function

void main(void) {
    TRISCbits.TRISC0 = 0; //using pin as output
    LATC = 0; //init to zero
    LATCbits.LATC0 = 1; //turn on the LED by writing to the latch
    while(1) continue; //sit here forever doing nothing
}
```

Fig.1. Lesson 1: working code snapshot – turning on an LED

1. Comments at the start of the code detailing the code author, version number and date.
2. Comments throughout the code explaining what the code is doing
3. Directives, which tell the compiler what libraries to include, how to process its inputs and outputs and define static variables to be used during compilation. This is a large subject, which we will not fully discuss here; it covers information about setting various PIC options; eg clock speed or watchdog disable.
4. Main program code

Directives

We have three programming *directives* in the code in Fig.1: `#define, #include and #pragma`. Let's look at each of these.

`#define` is used to set a variable to a fixed value, which can then be used throughout the code. Here, we set our internal clock frequency (referred to as _XTAL_FREQ) to 500,000Hz. This is important to note when performing timing calculations because it sets the speed of operation of the PIC and many of its dependent operations rely on this frequency.

`#include` tells us to include other pieces of code or headers; in this case, three header files: **stdio.h**, **stdlib.h** and **htc.h**. The file **stdio.h** is a standard input and output library file, which contains many pre-written functions that we can use; eg **printf()** and **scanf()**. The file **stdlib.h** is another standard library, which contains more functions; eg, **atoi** (convert string to integer) and **abs** (get absolute value). The file **htc.h** maps pins specific to our chosen PIC device – the PIC16F1829. It tells the compiler what each pin of our chosen PIC does. It's worth pointing out that for our very simple programs we won't use the functions from these files, but we certainly will in the future, so it's well worth getting into good habits and including these easy-to-add directives.

Both `#include` and `#define` are known as pre-processor directives because they are examined before the compilation of code.

`#pragma` is used to specify diverse options to the compiler, relating to the microcontroller and the compiler we use. It sets various parameters for the internal workings of the PIC. These are fixed values and are only set when programming our device. In our code, we set up our microcontroller in this order (with some brief mention of function):

- (FOSC=INTOSC) – the system clock is set to the internal oscillator
- (WDTE=OFF) – watchdog timer is disabled
- (MCLRE=OFF) – master clear external reset is disabled
- (CP=OFF) – code protection is off
- (BOREN=OFF) – brown out reset is off
- (CLKOUTEN=OFF) – clock out is disabled
- (IESO=OFF) – internal oscillator automatic switchover is disabled
- (FCMEN=OFF) – fail safe clock monitor is disabled
- (WRT=OFF) – write protection is off
- (PLLEN=OFF) – clock phase lock loop is disabled
- (STVREN=OFF) – stack overflow/underflow is disabled
- (LVP=OFF) – low voltage programming on MCLR/VPP is disabled.

You don't need to know what all of these mean at this stage, the key is to understand that when writing a program you need to give the compiler the information about how to set the PIC to perform as it executes the compiled code. For example, from our settings above, we see that the watchdog timer is disabled, this is set during programming time and cannot be enabled during the execution of the code in the PIC.

The main loop

Every bit of code we will ever write for PICs will contain something called the 'main loop'. In our code we have the following:

```
void main(void) {
}
```

All of our code to be executed is placed inside the curly braces. I'd love to explain the meaning of `void`, but it's a complicated concept, so for now just accept it is what you need to write for all your simple programs in this series. It is called the 'main loop' because once it finishes all the code within the curly braces, the PIC will reset itself and start the 'main loop' again.

Port setup and latching

When our code wants to communicate with the outside world it will use its general purpose input and output pins (GPIO for short). In Fig.2 we see the pin diagram of the PIC16F1829. There are 20 pins in total and each one is labeled with every function that it can provide. Our **htc.h** library file mentioned above maps our pin numbers to their internal port names. There are three ports in total, A, B and C. We can see that in our diagram port A consists of RA0, RA1 and RA2. Our pin-mapping file maps these port numbers to pins 19, 18 and 17 respectively on the physical device. We're interested in Port C for our code. Specifically we want to control bit 0 of port C, which is referred to as RC0 in the diagram – pin 16 of the physical PIC and to which our red LED is connected.

In Fig.3, there's a flow diagram of how we operate that specific pin on the device in order to control the LED. In our code, first we define if that pin is going to be an input or an output (TRIS). Then we set every pin on that port as low (LAT). Last, we select the single pin in Port C, bit 0 and we set that output as high.

`TRISCBITS.TRISC0 = 0;` refers to setting the TRIS register, which allows us to define if a specific port is an output or an input. An input is defined as a 1 and an output is defined as a 0. Thus we set bit 0 of port C as an output.

`LATC = 0;` sets all of port C to a low output. LAT refers to a latching of the output signal and in this case pulls the output signal low. It is not completely necessary to set every bit on port C low, but it is good practice.

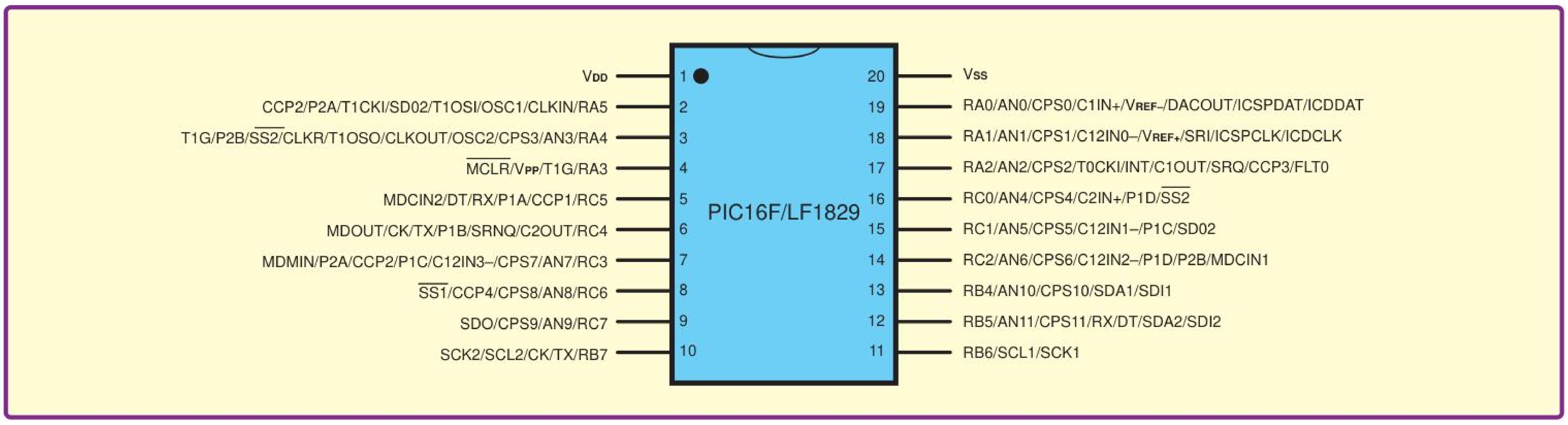

VDD
CCP2/P2A/T1CKI/SD02/T1OSI/OSC1/CLKIN/RA5
T1G/P2B/SS2/CLKR/T1OSO/CLKOUT/OSC2/CPS3/AN3/RA4
MCLR/VPP/T1G/RA3
MDCIN2/DT/RX/P1A/CCP1/RC5
MDOUT/CK/TX/P1B/SRNQ/C2OUT/RC4
MDMIN/P2A/CCP2/P1C/C12IN3–/CPS7/AN7/RC3
SS1/CCP4/CPS8/AN8/RC6
SDO/CPS9/AN9/RC7
SCK2/SCL2/CK/TX/RB7
1
2
3
4
5
6
7
8
9
10
PIC16F/LF1829
20
19
18
17
16
15
14
13
12
11
VSS
RA0/AN0/CPS0/C1IN+/VREF–/DACOUT/ICSPDAT/ICDDAT
RA1/AN1/CPS1/C12IN0–/VREF+/SRI/ICSPCLK/ICDCLK
RA2/AN2/CPS2/T0CKI/INT/C1OUT/SRQ/CCP3/FLT0
RC0/AN4/CPS4/C2IN+/P1D/SS2
RC1/AN5/CPS5/C12IN1–/P1C/SD02
RC2/AN6/CPS6/C12IN2–/P1D/P2B/MDCIN1
RB4/AN10/CPS10/SDA1/SDI1
RB5/AN11/CPS11/RX/DT/SDA2/SDI2
RB6/SCL1/SCK1

Fig.2. Pin out diagram of PIC16F1829 with individual pin functions

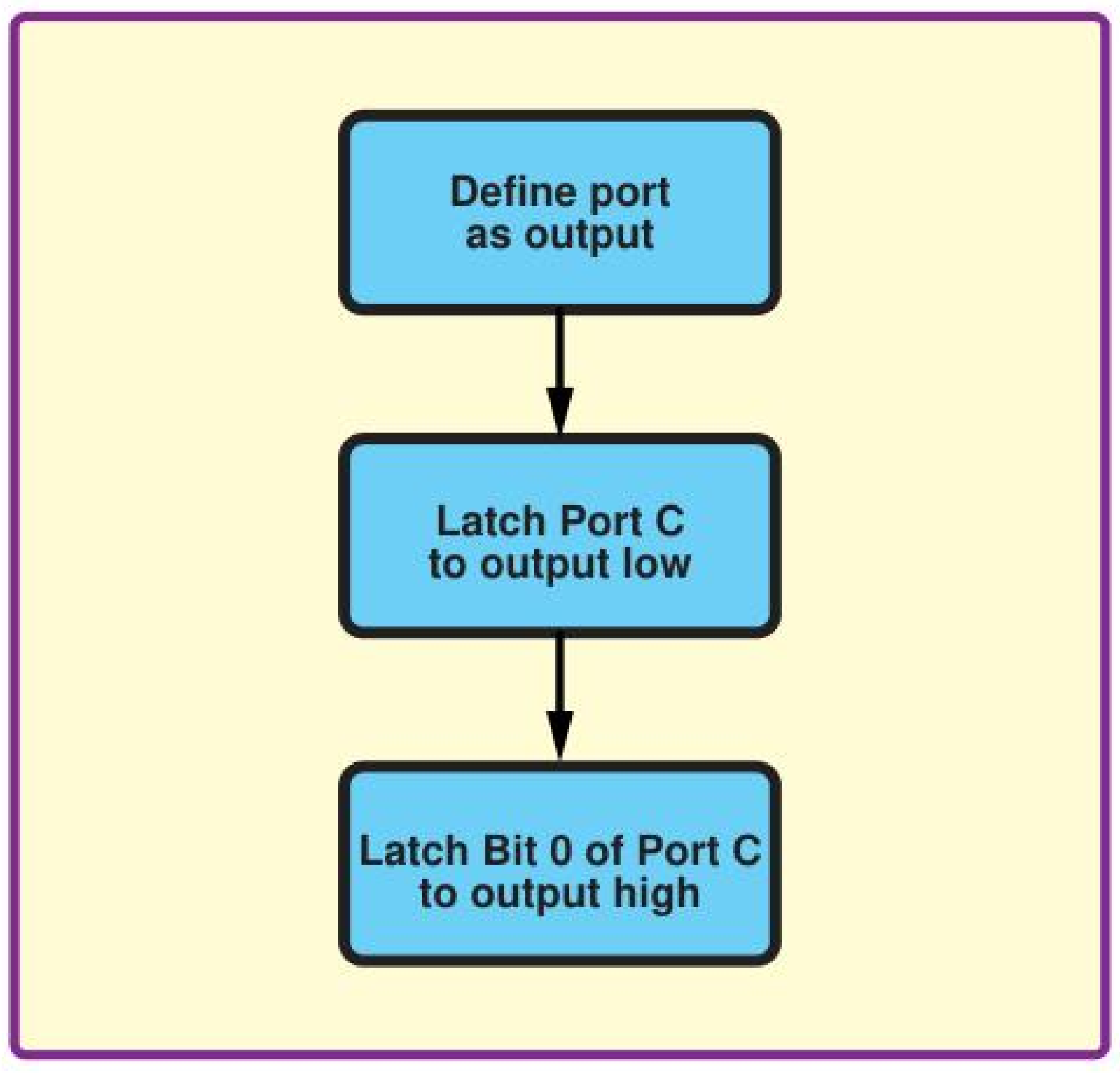


Fig.3. Lesson 1: flow chart – turning on an LED

`LATCbits.LATC0 = 1;` selects only bit 0 of port C and latches the output signal to a logic high. Since the cathode of our LED is connected to ground and RC0 is connected to the anode of our LED, when this signal is latched high, the LED will illuminate.

LATC is used to refer to all of the bits in Port C (this includes RC0, RC1, RC2, RC3, RC4, RC5, RC6 and RC7). `LATCBITS.LATC0` selects only Bit 0 of Port C, also known as RC0 or Pin 16.

The while loop

The `while` loop is a very useful function. It repeatedly executes the code enclosed inside its curly braces. In the following code, the function `someAction()` will be performed while the `someValue` variable is equal to 1. If it equals 0, then it will exit out of the loop. The variable `someValue` is known as the 'test condition' or 'expression', as it is tested to see if it is equal to 1.

```
while(someValue) {
        someAction();
}
```

Alternatively, if our `while` loop only performs one small action then it can be written in a single line as follows:

```
while(someValue) someAction();
```

Or as it is in our code:

```
while(1) continue;
```

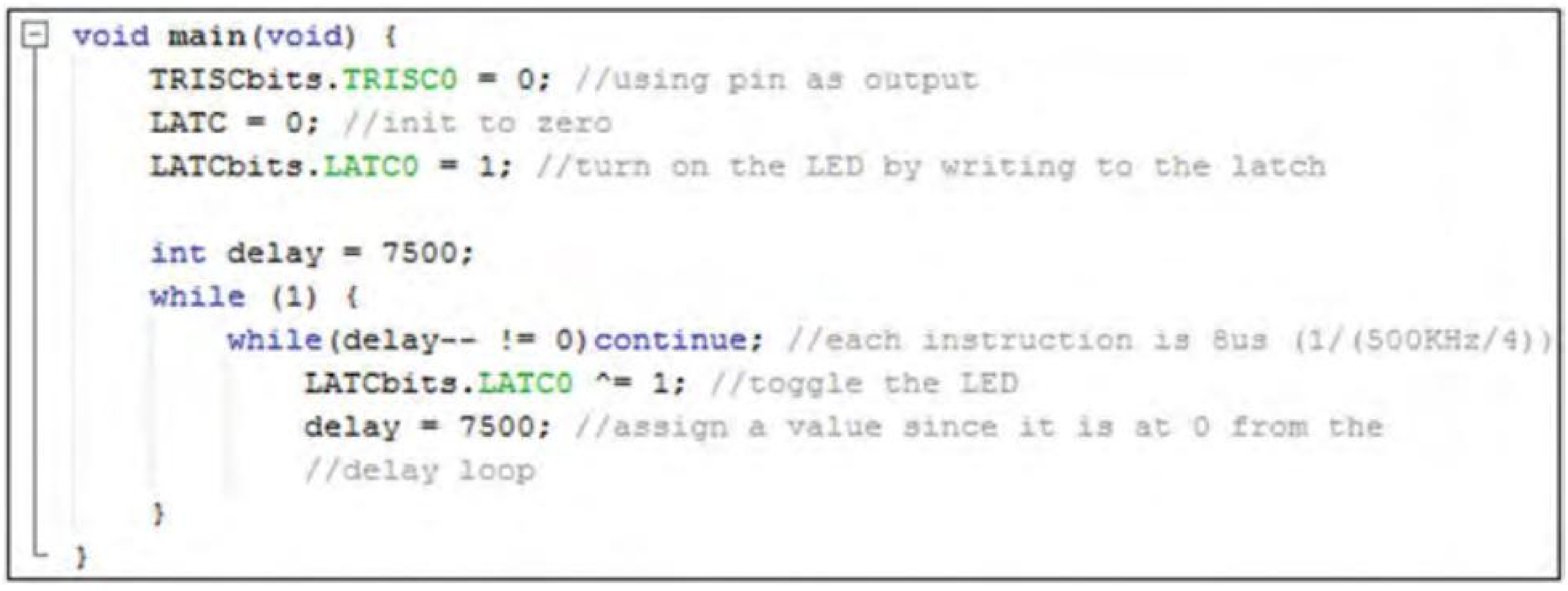
In this case, we can get away with not using the curly braces. Since the test condition is 1, it will never change, therefore it will stay in this loop indefinitely. Using the variable `someValue` means the variable can be changed to a 0 at some point (maybe in `someAction()`) and then exit the loop. The word `continue` is a controlling statement specifically for the while loop function, which moves onto the next iteration of the while loop. It is not completely necessary, but it is good practice to use it to control the loop properly.

Lesson 2

We've now turned on the LED, but that's just the start! In this lesson we turn the LED on… and then off for a period of time to make it blink. In Fig.4 we have our 'main loop' code. Taking what we did in Lesson 1, replace the 'main loop' with the contents of Fig.4.

Our code is now ready to go. Plug your Low Pin Count Demo Board into an available USB port and click 'Make and Program' (represented by a green down arrow in MPLAB X). Our red LED should now blink.

We've added a few more lines into our code to make it blink. We'll go through them one by one. Fig.5 shows a flowchart of how our code works, starting off with what we had in Fig.3.



```
void main(void) {
    TRISCbits.TRISC0 = 0; //using pin as output
    LATC = 0; //init to zero
    LATCbits.LATC0 = 1; //turn on the LED by writing to the latch

    int delay = 7500;
    while (1) {
        while(delay-- != 0)continue; //each instruction is 8us (1/(500KHz/4))
            LATCbits.LATC0 ^= 1; //toggle the LED
            delay = 7500; //assign a value since it is at 0 from the
            //delay loop
    }
}
```

Fig.4. Lesson 2: working code snapshot – blink the LED

Moving on from what we did in Lesson 1, we skip over the port definitions and latches and move onto the next line, where we define a variable called `delay` as an integer (shortened to `int` in C) and then we store the value 7500 in that variable `delay`. An integer in our PIC is a 16-bit binary representation of a decimal number. Take the number 311 in decimal, in binary this is represented as 1 0011 0111, which is only 9-bits long. 16-bit integers can hold a value as high as 65,535 (which is 1111 1111 1111 1111 in binary). It is assumed in our code that this is an unsigned integer, which ranges from 0 to 65,535. A signed integer means that one of the bits is assigned a 1 or a 0 to represent a positive or a negative number. Two's complement 16-bit signed integers range from –32768 to 32767 (1000 0000 0000 0000 and 0111 1111 1111 1111).

Then we enter our forever `while` loop again (`while(1)` mentioned earlier). In this loop, all of our code is encapsulated between the curly braces. Next, we enter into a second `while` loop inside our original one. In this loop, we repeatedly test an equation inside the brackets until it is no longer equal to 1. Let's look at the equation used: `delay-- != 0`

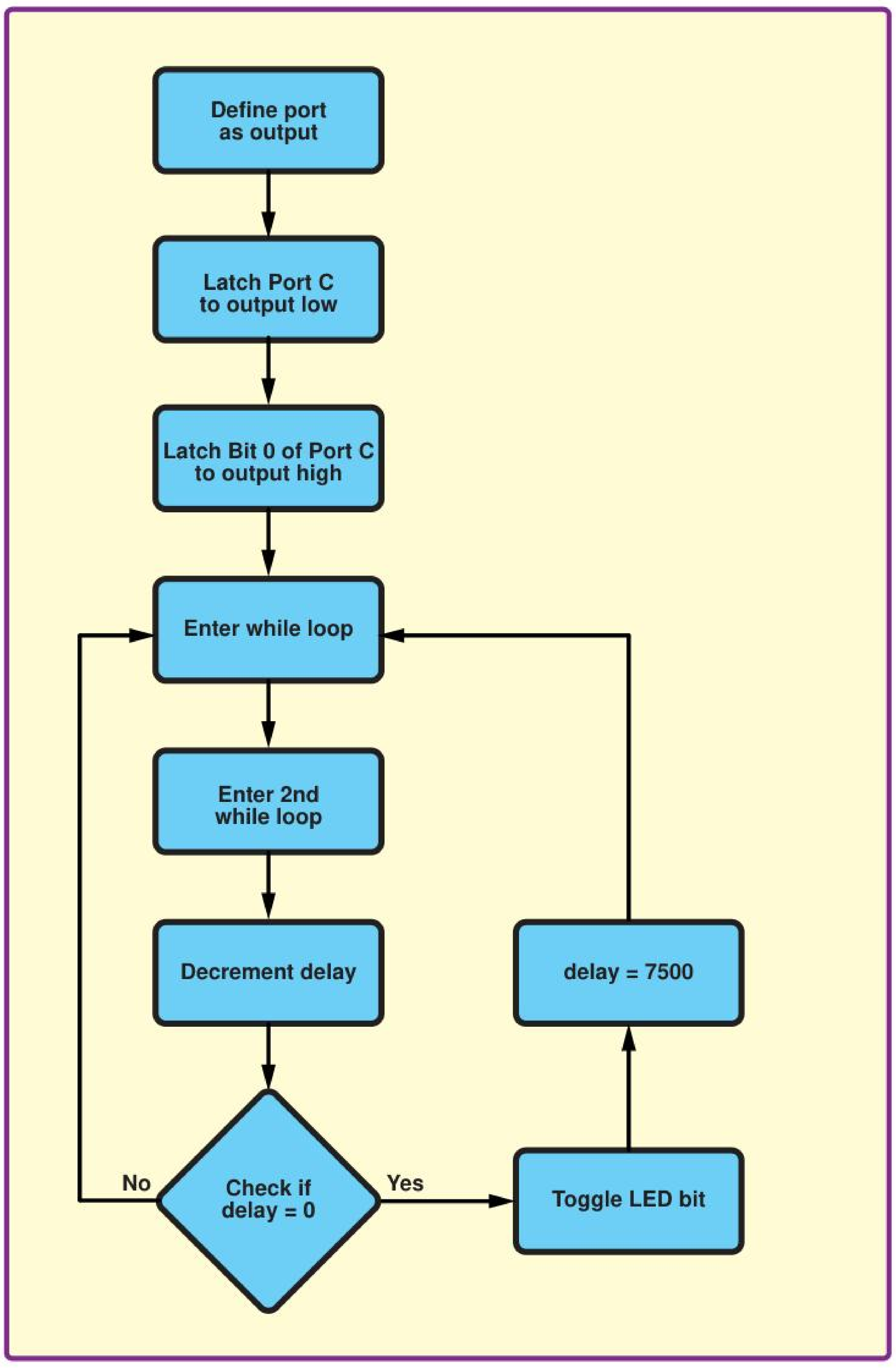


Fig.5. Lesson 2: flow chart – blink the LED

A number of things are going on here. It is useful to note in any equation in any programming language, we read from right to left just like in Arabic (the opposite to how we read this article). So instead of looking at ‘delay’ first, we focus on the 0 and `!=` terms. `!=` is a comparison operator. It checks to see if the item on the right is not equal to the item on the left of it. This is our test equation for the `while` loop. If the item on the right is not equal to the item on the left, then the test equation will return true or a 1 to the `while` loop. In this case, we compare the variable `delay` with a 0, as long as these two values are not equal, it will return a 1.

Now we look at the variable `delay--`. We know the `delay` variable is equal to 7500, but what are the two minuses after the number? These are known as post-decrement operators. Once our comparison is done checking that 7500 is not equal to 0, we take the value stored in `delay`, subtract one and store our new value (now 7499) back into `delay`. Note this is done after the comparison operator, hence the name ‘post-decrement’ (after). Since this is in a `while` loop, we keep performing this subtraction until eventually `delay` is equal to zero. Now our test expression checks to see if `delay` (now 0) is not equal to 0, meaning this statement is false, giving us a return value to our `while` loop of zero, which exits the out of the loop to our next command.

Moving onto the next line, we have what looks like a latch, but with a small difference. Instead of just setting bit 0 of port C with a 1, we use a toggle operator instead: ^=. Toggling the output means if it was zero, it is set to a one. If it was one, then it is set to zero.

The last line in the new code sets our variable `delay` (which is currently equal to zero), back to having a value of 7500. The main `while` loop is now complete and it will run again.

It is interesting to note where the value 7500 comes from and how this blinks the LED at a rate of approximately one second. Recall that we set our internal clock to 500,000Hz earlier. The PIC divides that by 4 internally, which gives us a frequency of 125,000Hz. The reciprocal of this gives us our time for each instruction, which is 8µs. The `while` loop takes roughly 14 instructions to complete, this gives us 0.000008 × 7500 × 14 = 0.84 seconds, ie, roughly a second.

Try a simple test and speed up the blinking LED by halving the value 7500 to 3750, or slowing it down by doubling it to 15000.

Next month

We’ve covered quite a lot of the basics over the last few months. I’m going to try and keep the momentum and tackle another two lessons next month. Lesson 3 and 4 cover rotating LEDs and analogue-to-digital converters.

Not all of Mike’s technology tinkering and discussion makes it to print.

You can follow the rest of it on Twitter at @*MikePOKeeffe*, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com*

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AUDIO OUT

By Jake Rothman

Super-simple retro amp-speaker combo – Part 3

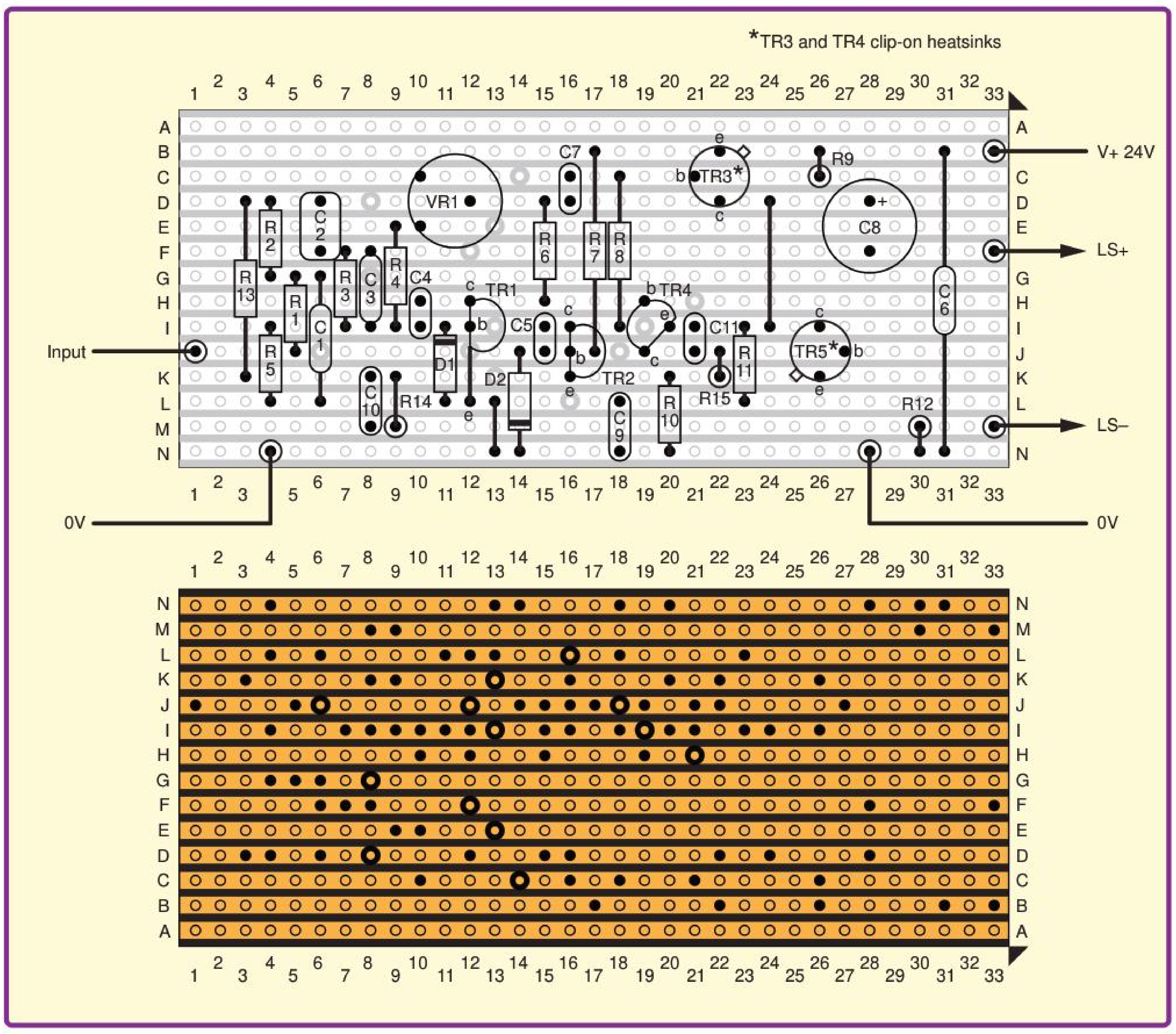


Fig.21. Veroboard layout for the Super-Simple Retro Amplifier

In Parts 1 and 2 of this article (*EPE*, June and August 2016) we looked at the design of an unusual 'retro' amplifier-speaker combination. Now, in Part 3, it's time to build the amplifier.

Veroboard design

I started off building this circuit on stipboard / Veroboard, as shown in Fig.17 last month – this is the circuit shown in Fig.15, also last month. Fig.21 shows the layout for this version. Construction is straightforward, just follow the coordinates and you can't go far wrong. However, as the design progressed I thought it would be fun to make a dedicated PCB, and since this is a retro design I used old-fashioned drawing and manufacturing techniques (no CAD or computers used), which I will now describe.

Retro pcb design and manufacture

The fully assembled PCB-based version is shown in Fig.22, and the circuit diagram and PCB design with track and overlay are shown in Fig.23 and Fig.24. You can download the design from the *EPE* website and its wide-track pattern can be etched in a Tupperware dish in the kitchen or school workshop. The 'period feel' has been emphasised by the use of Chartpak to draw the design. This meant using sticky pads and tracks to draw the layout. Fig.25a to Fig.25i shows how I did it. I'm surprised how inefficient most software packages are when designing single-sided discrete analogue layouts – handmade can still be a good way to do things!

Uprating

A great advantage of this design is its thermal stability. Unlike a normal push-pull class-AB output stage there is much less chance of thermal runaway and no possibility of an I_q preset being set too high. So it is relatively easy to uprate, assuming you can get enough heatsinking. I've taken a module up to 15W RMS into 8Ω with 9.9 °C/W heatsinks. The catch with this circuit is high frequency stability and after making the PCB and trying many different transistors, I found the RC values could be further optimised. For example 'slow' transistors, such as the TIP41/2 with an f_t of 3MHz, need C5 to be 3.3nF. I also reduced resistor R5 and R6, increasing the current through TR1 to 0.3mA to improve the slewing. A small 'snivet' (an unwanted high-frequency oscillation) at positive clip was also observed with slow devices, as shown in Fig.26. This was fixed with a 100nF bypass capacitor

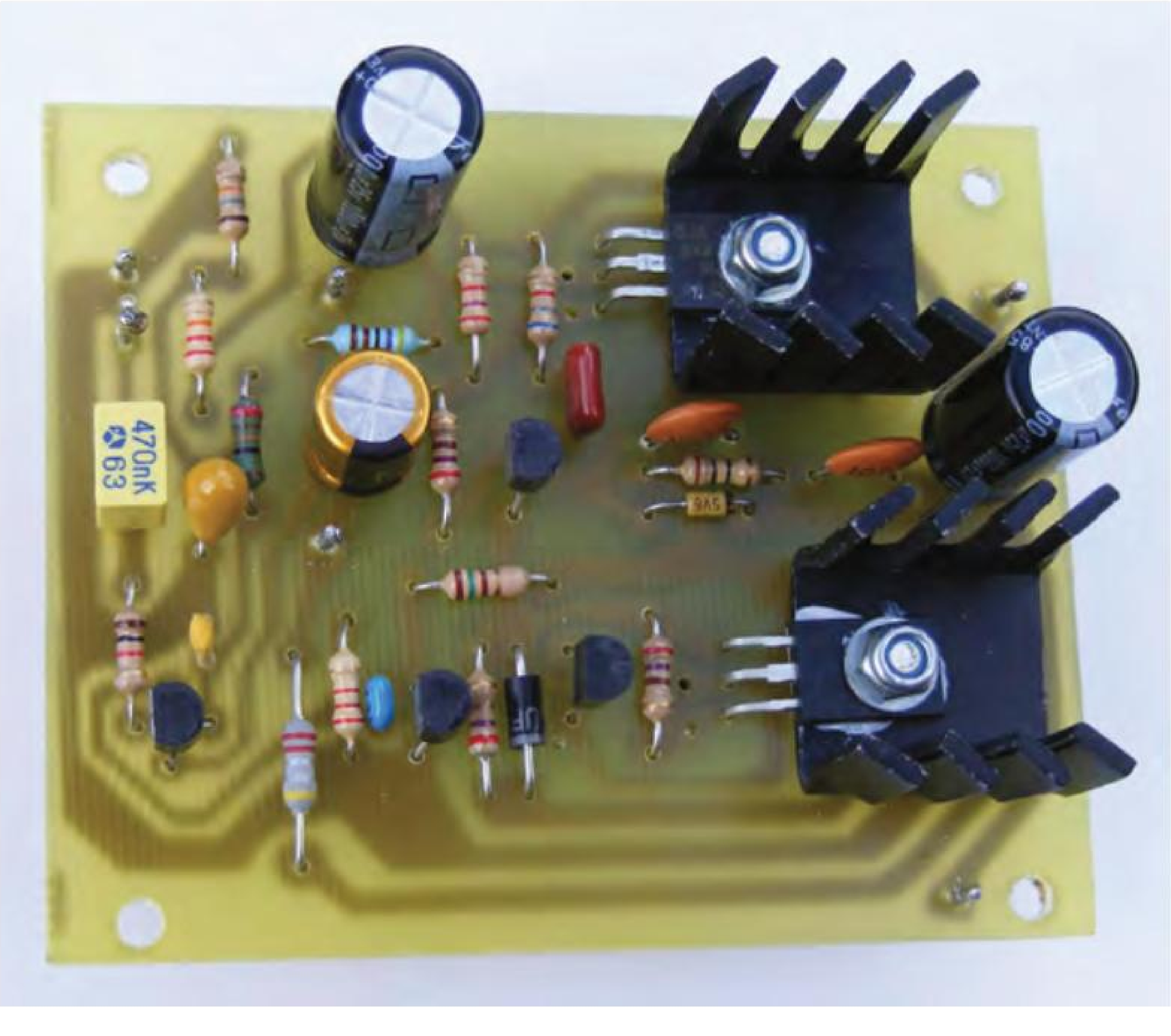


Fig.22. Super-Simple Retro Amplifier *built on a PCB – an ideal first-time discrete amplifier for hobbyists, tinkerers and audio fans!*

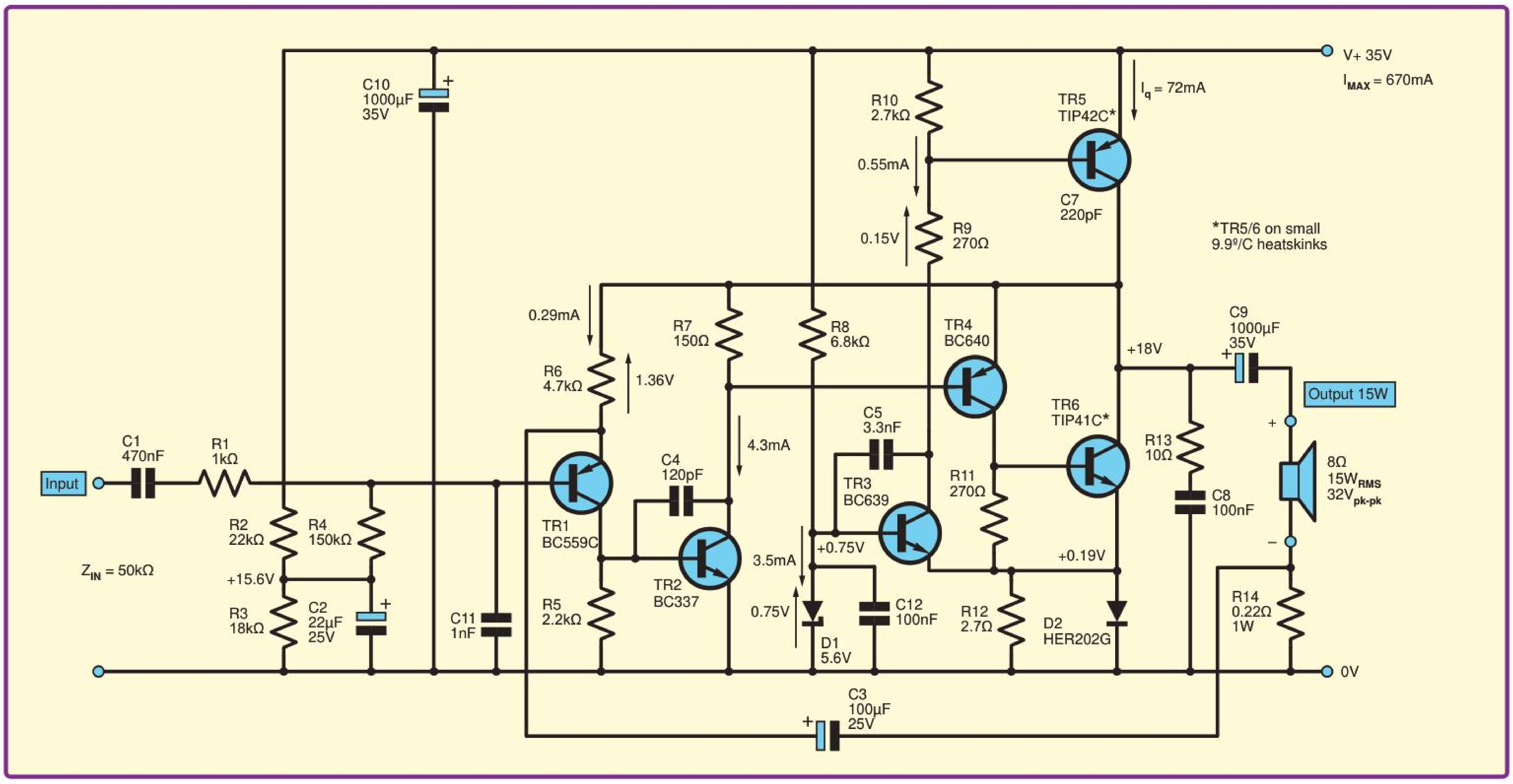
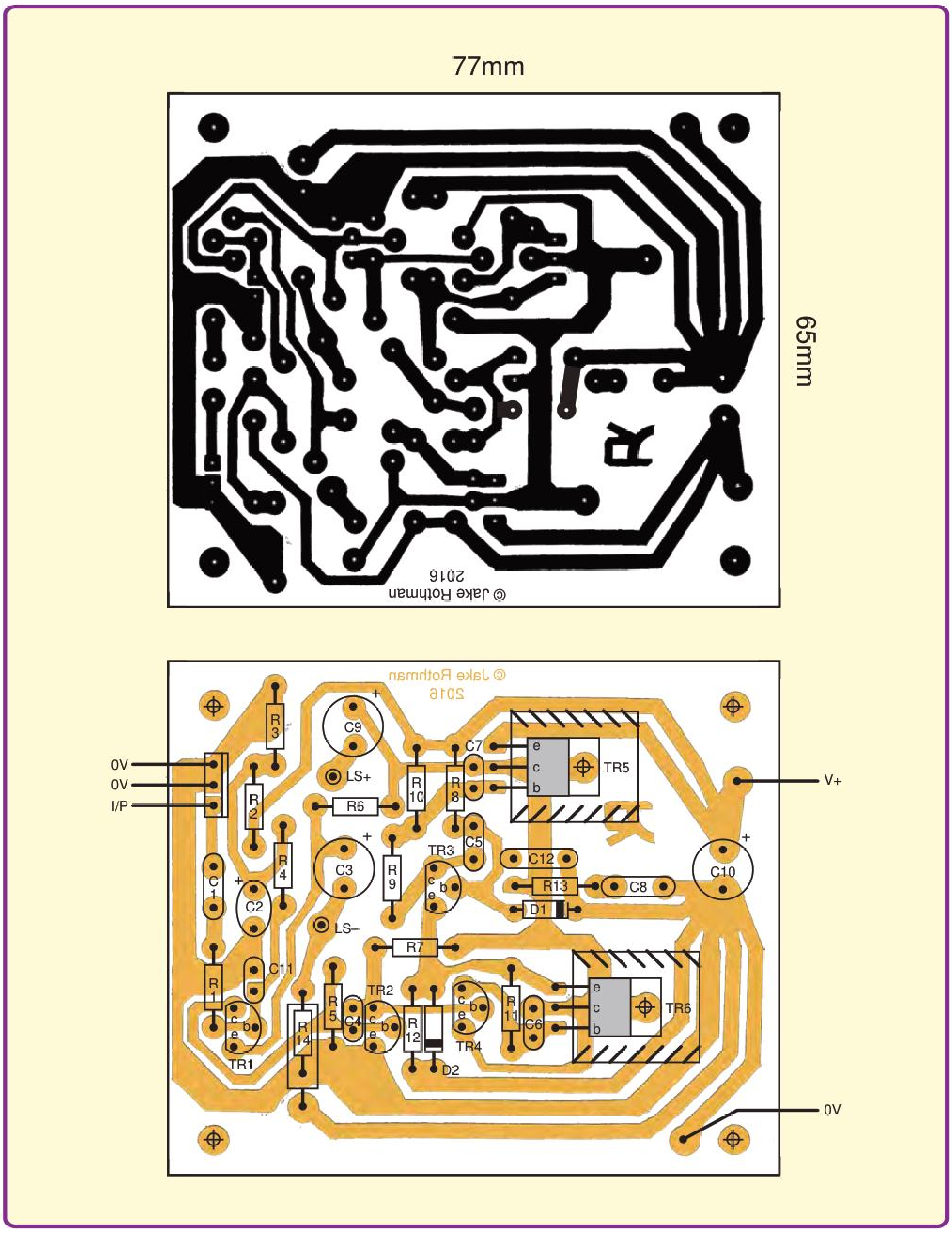

V+ 35V
I$_{MAX}$ = 670mA
C10
1000µF
35V
R10
2.7kΩ
0.55mA
I$_q$ = 72mA
TR5
TIP42C*
C7
220pF
0.15V
R9
270Ω
*TR5/6 on small
9.9º/C heatskinks
0.29mA
R7
150Ω
R8
6.8kΩ
TR4
BC640
C9
1000µF
35V
+18V
R6
4.7kΩ
1.36V
TR6
TIP41C*
Output 15W
C5
3.3nF
R13
10Ω
4.3mA
C1
470nF
R1
1kΩ
C4
120pF
TR3
BC639
R11
270Ω
8Ω
15W$_{RMS}$
32V$_{pk-pk}$
Input
C8
100nF
R2
22kΩ
R4
150kΩ
TR1
BC559C
+0.75V
Z$_{IN}$ = 50kΩ
3.5mA
+0.19V
+15.6V
TR2
BC337
R14
0.22Ω
1W
R3
18kΩ
C2
22µF
25V
C11
1nF
R5
2.2kΩ
0.75V
C12
100nF
R12
2.7Ω
D2
HER202G
D1
5.6V
0V
C3
100µF
25V

Fig.23. Super-Simple Retro Amplifier – *uprated to 15W into 8Ω running off 35V*


77mm
65mm
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0V
0V
I/P
V+
0V
R3
C9
C7
TR5
R2
LS+
R10
R8
R6
R4
C3
R9
TR3
C5
C12
R13
C8
C10
C1
C2
LS–
D1
R7
C11
R1
R14
R5
C4
TR2
R12
TR4
D2
R11
C6
TR6
TR1
e
c
b

Fig.24. Super-Simple Retro Amplifier *PCB track layout and component overlay*

C12 across the voltage reference D1. I also found I could leave off C6 and C7 with the bigger output transistors I used. I've left the pads on, just in case some reader's transistors may need them. I tried out several diodes for D2, and the best for the higher power boards is the HER202G, a fast 200V 2A device (RS part 688-1940P). It's not easy to squeeze in a 3A UF5404, although I did just about do it – see Fig.27.

Suitable transistors

Fast output devices give a cleaner high-frequency response: BD139/40 up to 5W, 24V into a 15Ω load; transistor type MJE243G/253G up to 10W, 35V into a 15Ω load. The BD436/7 will also do, but they are slow and only give 7.5W into 8Ω at 24V. If you want more power, 15W$_{rms}$ into 8Ω with 35V is about the limit for the board size. Suitable transistors are the TO220 case types, TIP41/2, BD2243/4 and BD911/2, but note that these are all slow. It is vital to remember these have a reversed pinout and go metal side up, the opposite to the TO126 types. I used BC639/40s for TR3 and 4 and

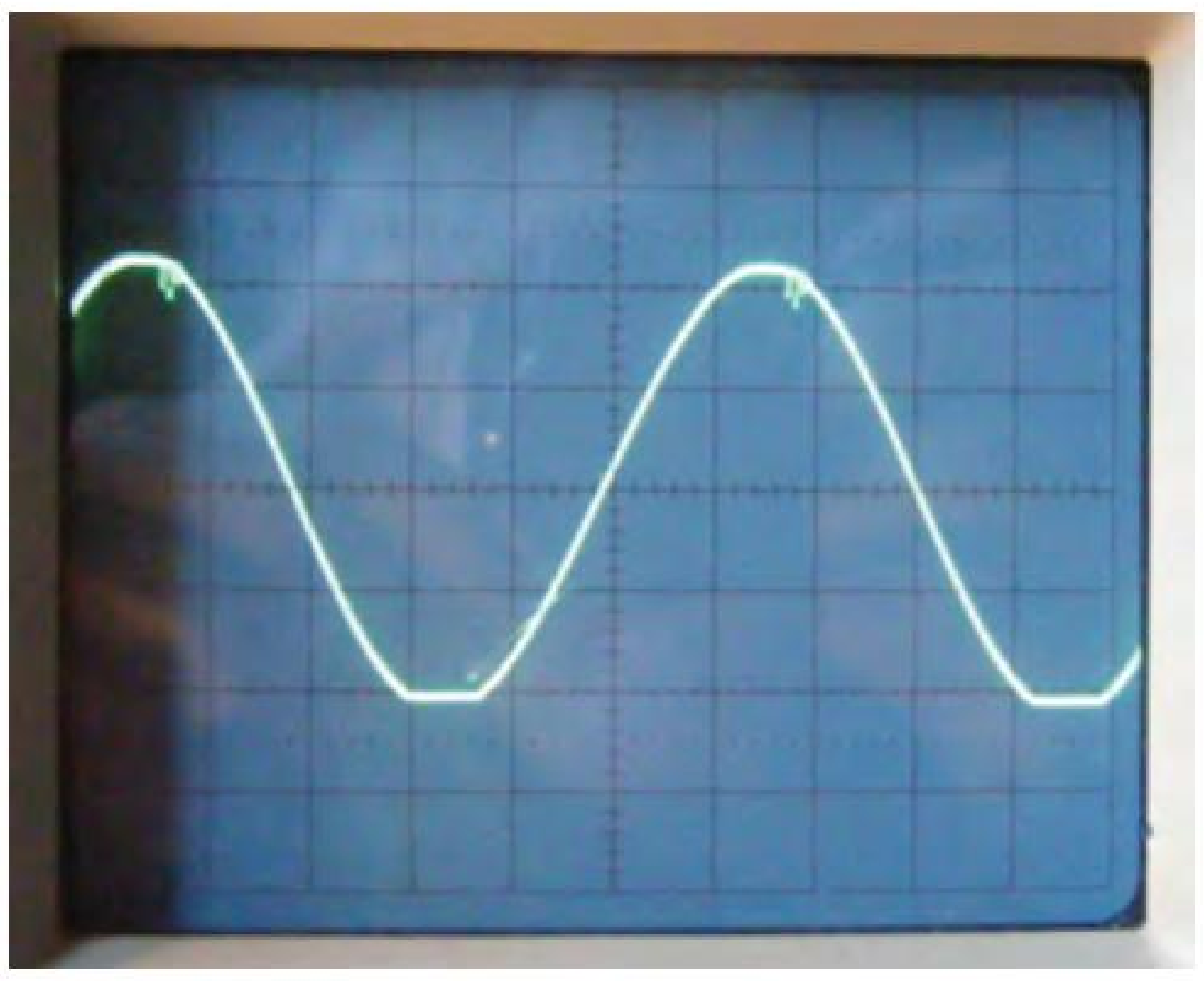


Fig.26. A nasty snivet, or high frequency oscillation burst – fixed by decoupling D1.

these have the collector in the middle and have to be inserted differently (see Fig.27). The current sense resistor R14 has to be scaled to the speaker impedance: 0.47Ω for a 15Ω speaker. If current sensing is not required, then a normal non-inverting amplifier configuration can be made by using a 220Ω resistor for R14 and putting it in the smaller footprint position. The unused hole is now the speaker negative to earth.

Component list for PCB version

Resistors

R1	1kΩ
R2	22kΩ
R3	18kΩ
R4	150kΩ metal-film
R5	2.2kΩ
R6	4.7kΩ metal-film
R7	150Ω
R8	6.8kΩ
R9, R11	270Ω
R10	2.7kΩ
R12	2.7Ω
R13	10Ω
R14	0.22Ω (for 8Ω speaker)

All 0.25W 5% carbon film unless otherwise stated.

Capacitors

C1	470nF polyester
C2	22µF 25V
C3	100µF 25V
C4	47pF (120pF for slow transistors)
C5	1nF (3.3nF for slow transistors)
C6, C7	not used optional
C8, C12	100nF ceramic 20%
C9, C10	1000µF 25V to 1500µF 35V (high power)
C11	1nF ceramic 10%

Semiconductors

TR1	BC559C
TR2	BC337
TR3	BC337 or BC639 (high power)
TR4	BC327 or BC640 (high power)
TR5	MJE253G or TIP42C (high power)
TR6	MJE243G or TIP41C (high power)
D1	5.6V or any voltage BZY88 zener
D2	UF4004 or HER202G (high power) fast rectifier

Miscellaneous

Heatsinks TO220 x2 (21°C/W for low power design, 9.9 °C/W, high power).

Making a PCB the old-fashioned way

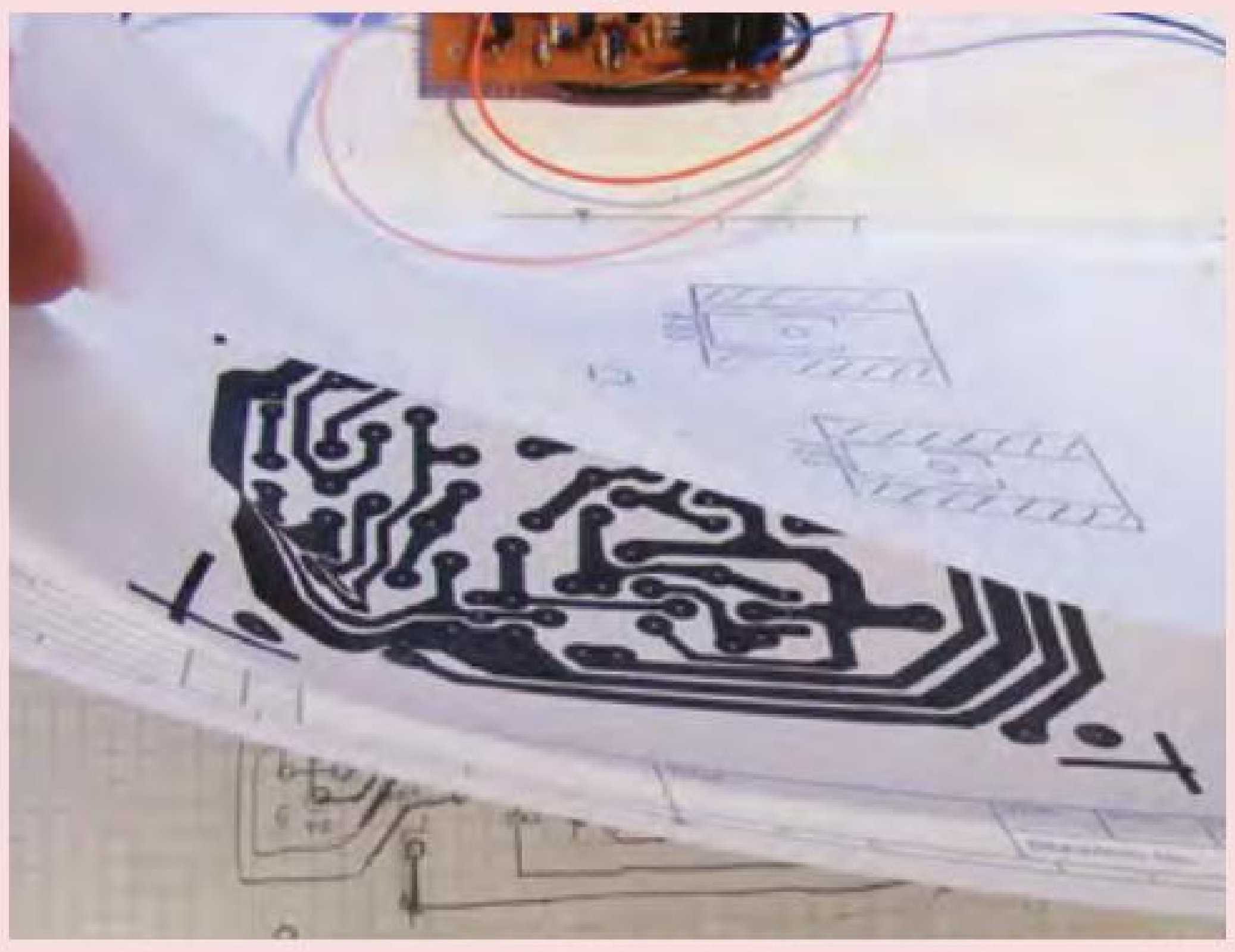


Fig.25a.The retro way of doing PCBs – using tape in double size on top of a pencil drawing on 0.2-inch grid paper. The artwork is scanned and reduced for printing on film using MS Paint, Photoshop or other graphics programs.

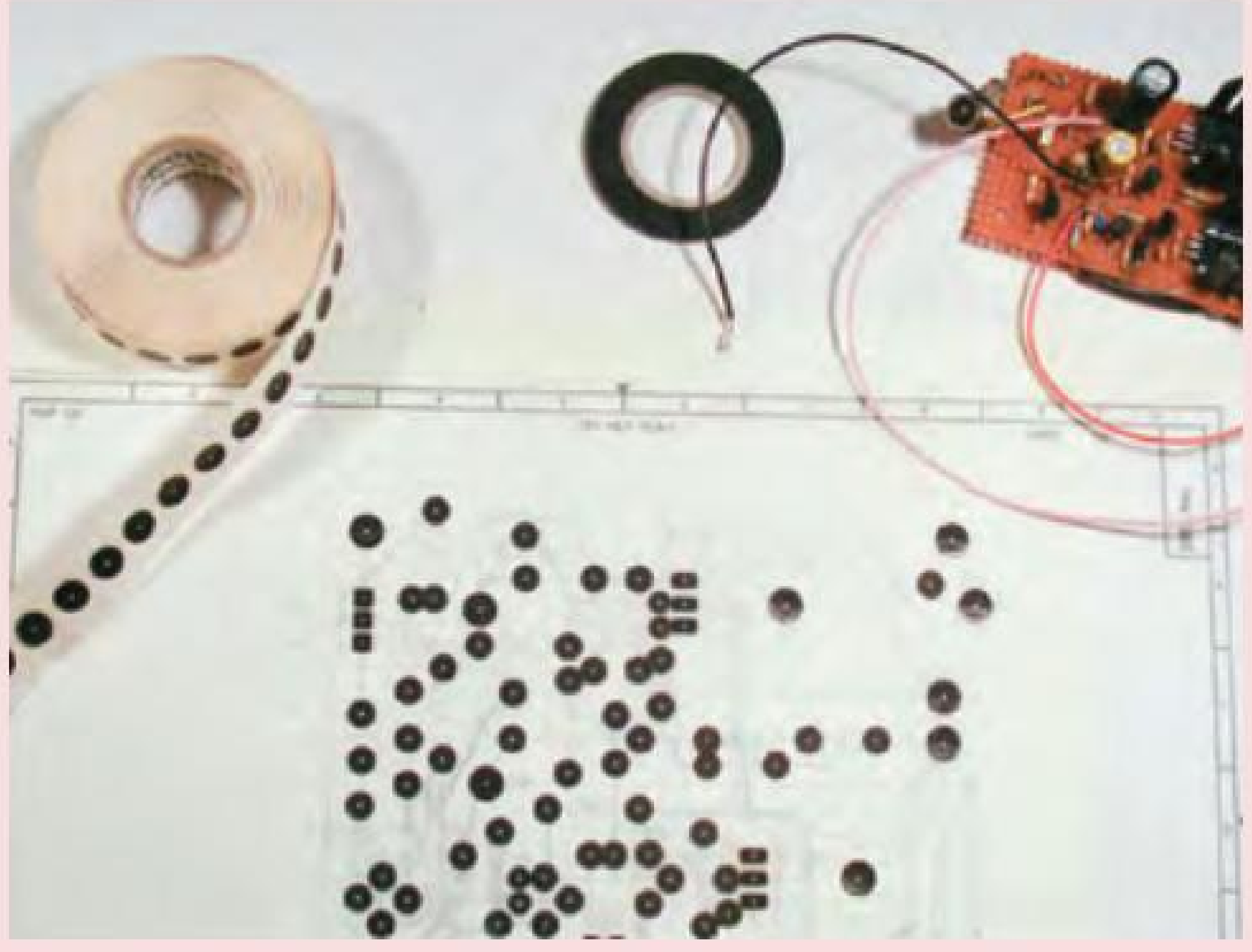


Fig.25b. First, stick solder connection pads onto the drafting film.

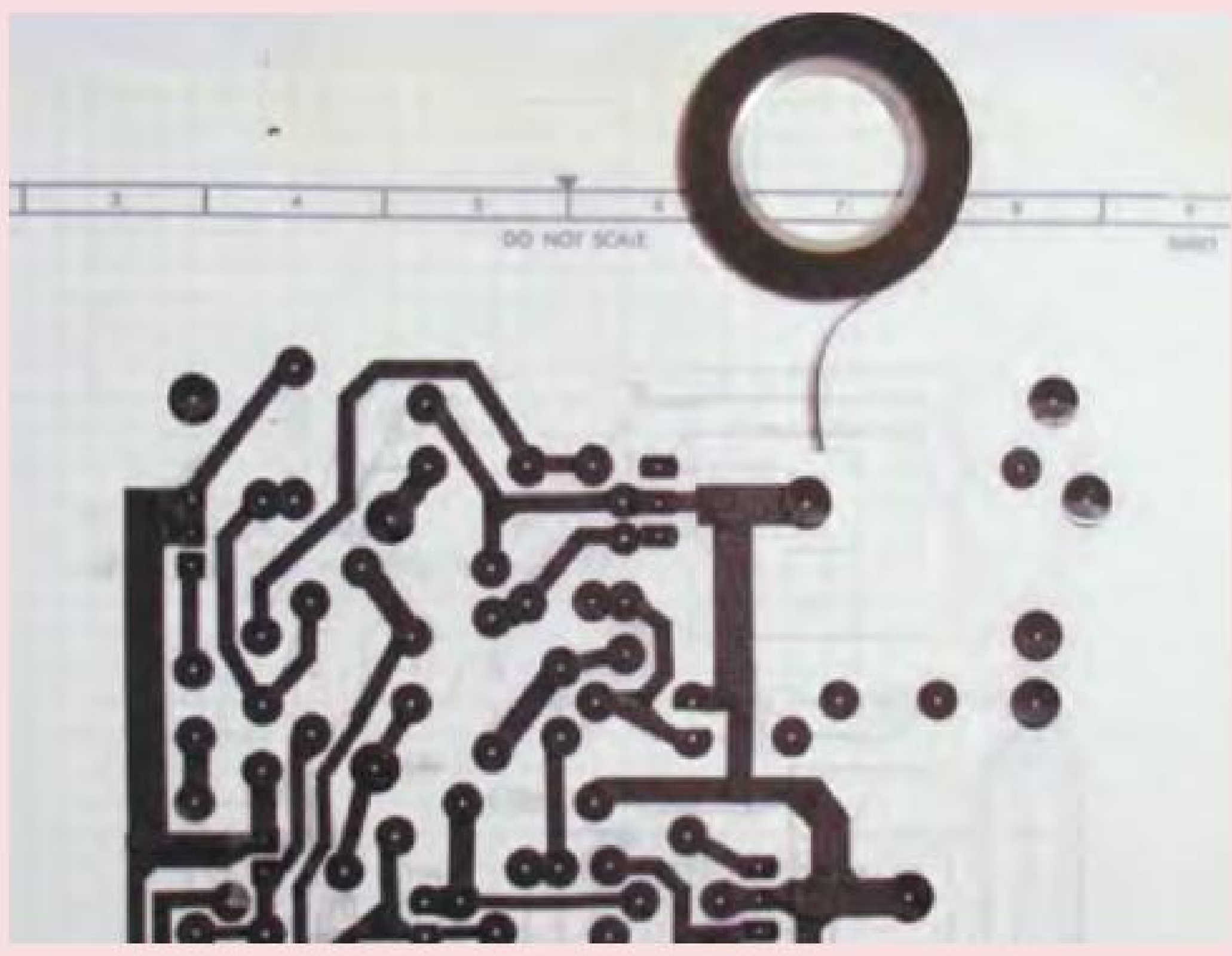


Fig.25c. Second, connect the pads with tape.

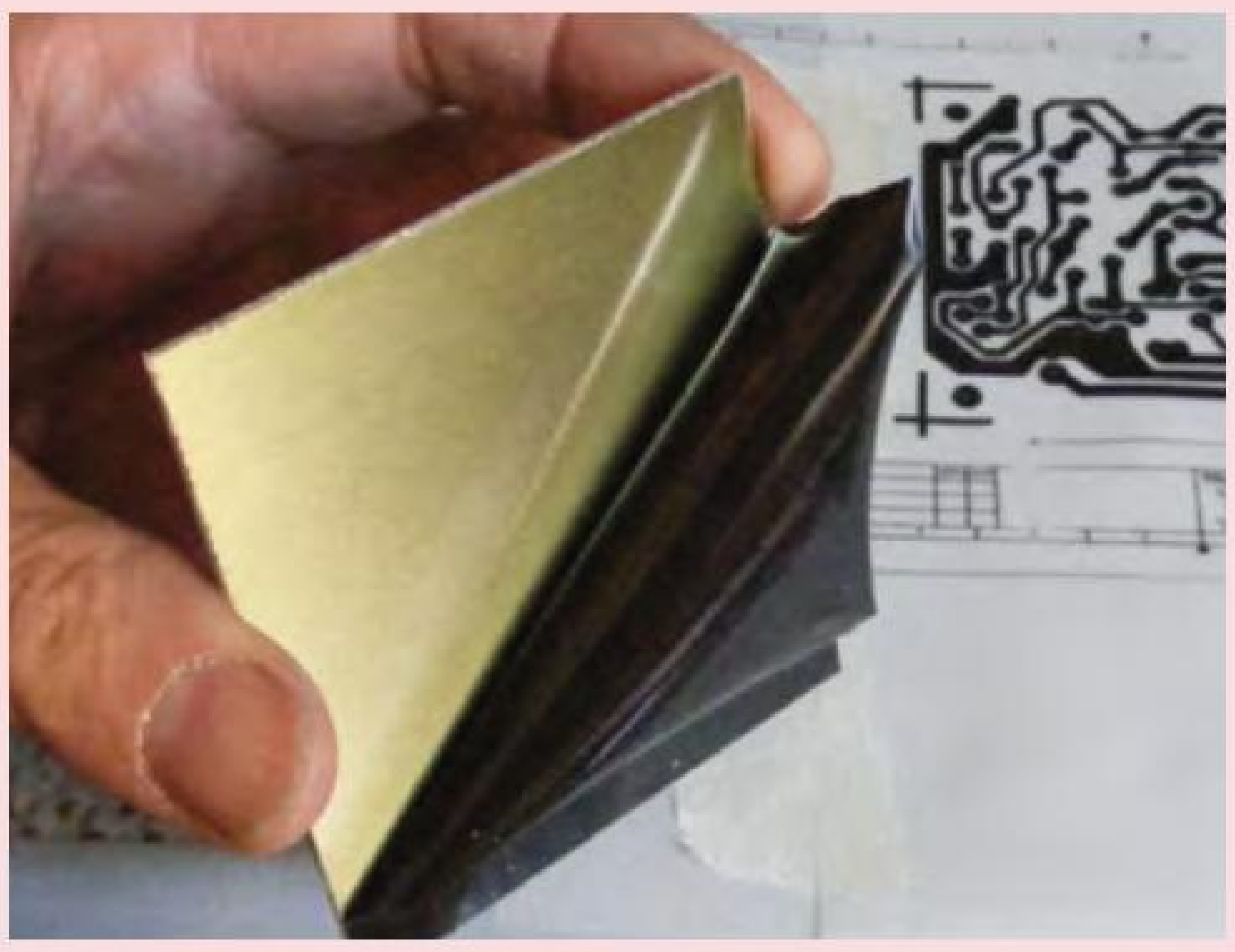


Fig.25d. Ready for exposing the pre-coated board to UV light. Note two Rapid Laserstar films are stuck together to increase contrast. The light leaking through unintended holes in the print are like noise, they don't coincide, so the black gets much blacker.

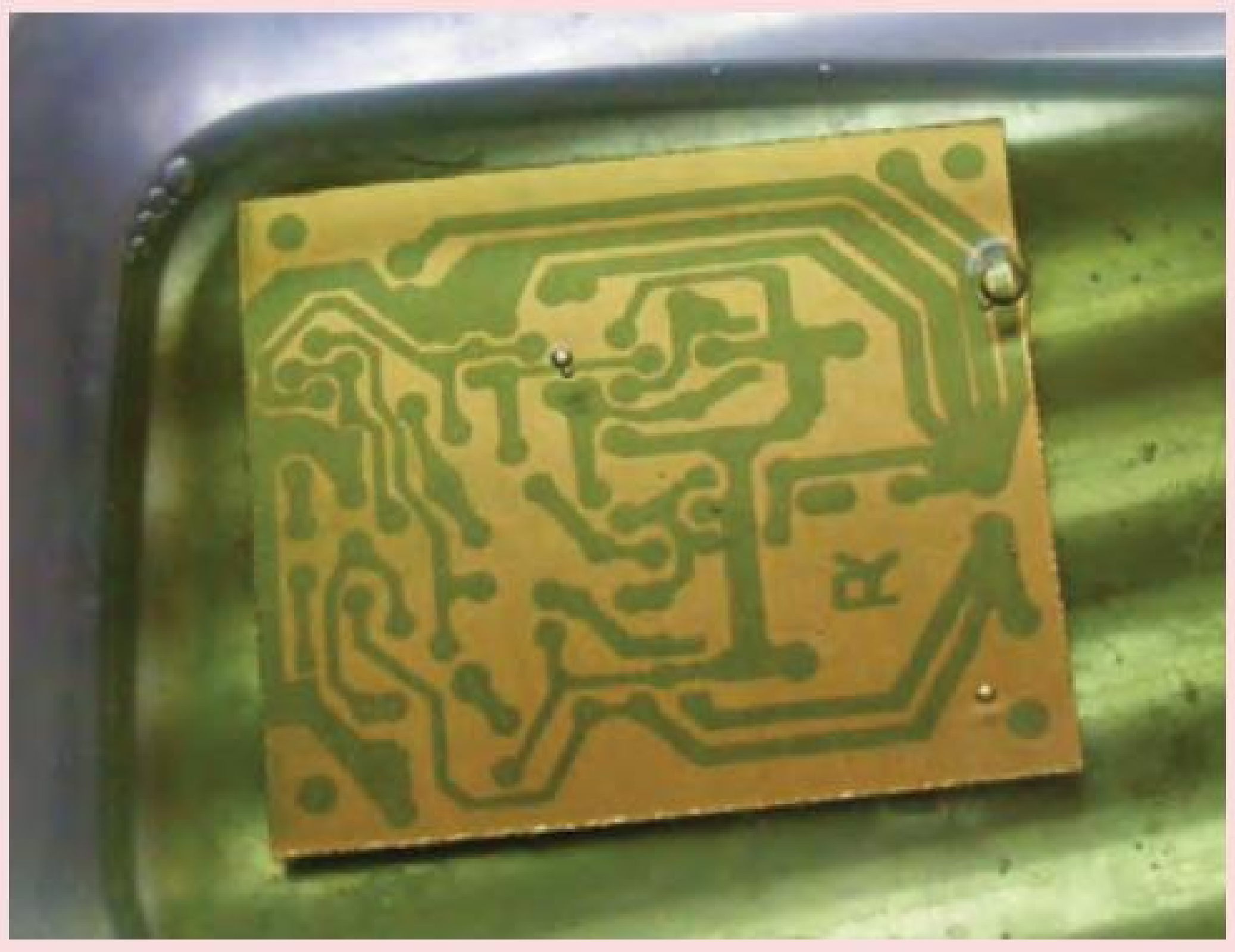


Fig.25e. Developing the exposed board – the magic bit!

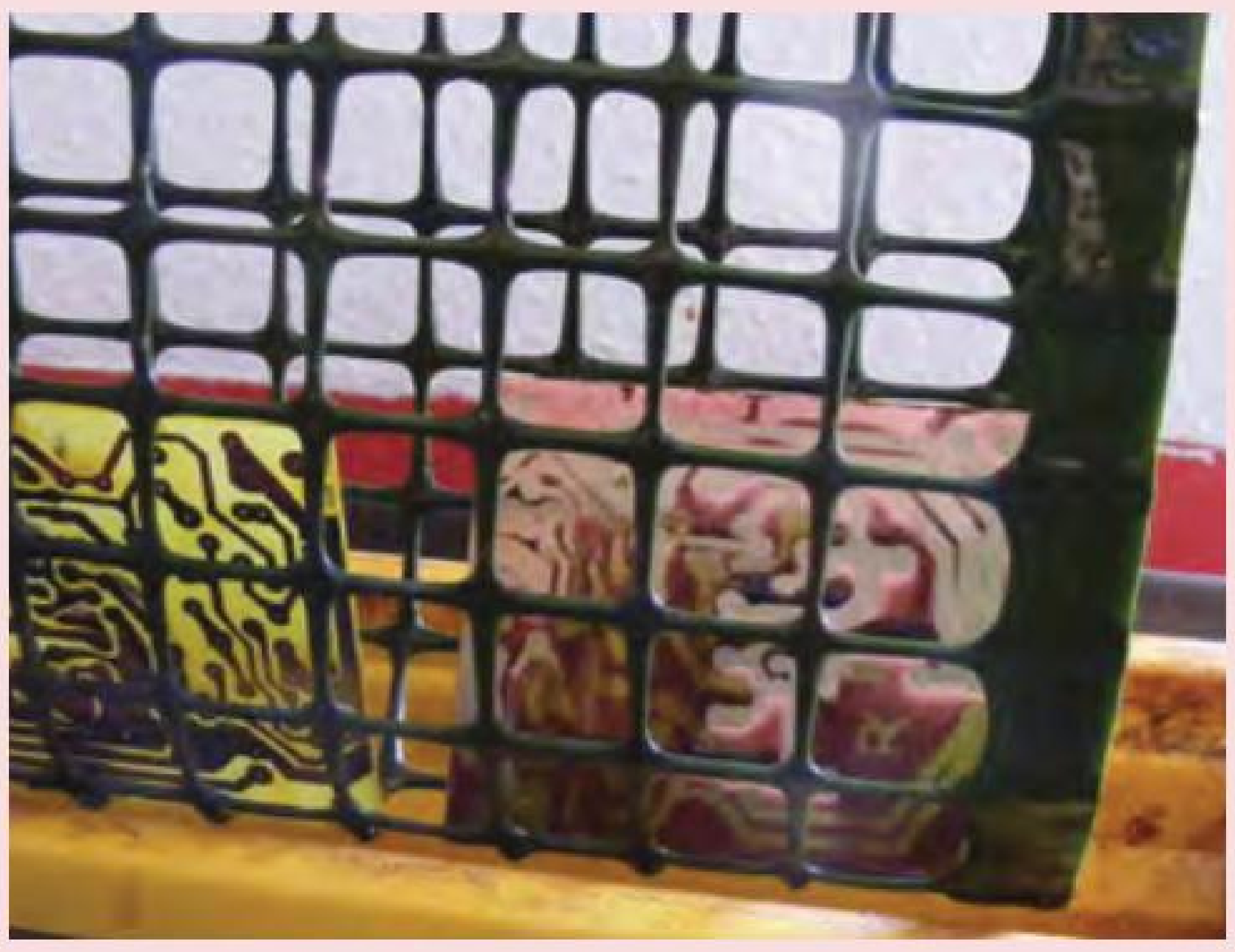


Fig.25f. Etching the board to reveal the tracks and pads – the messy bit.

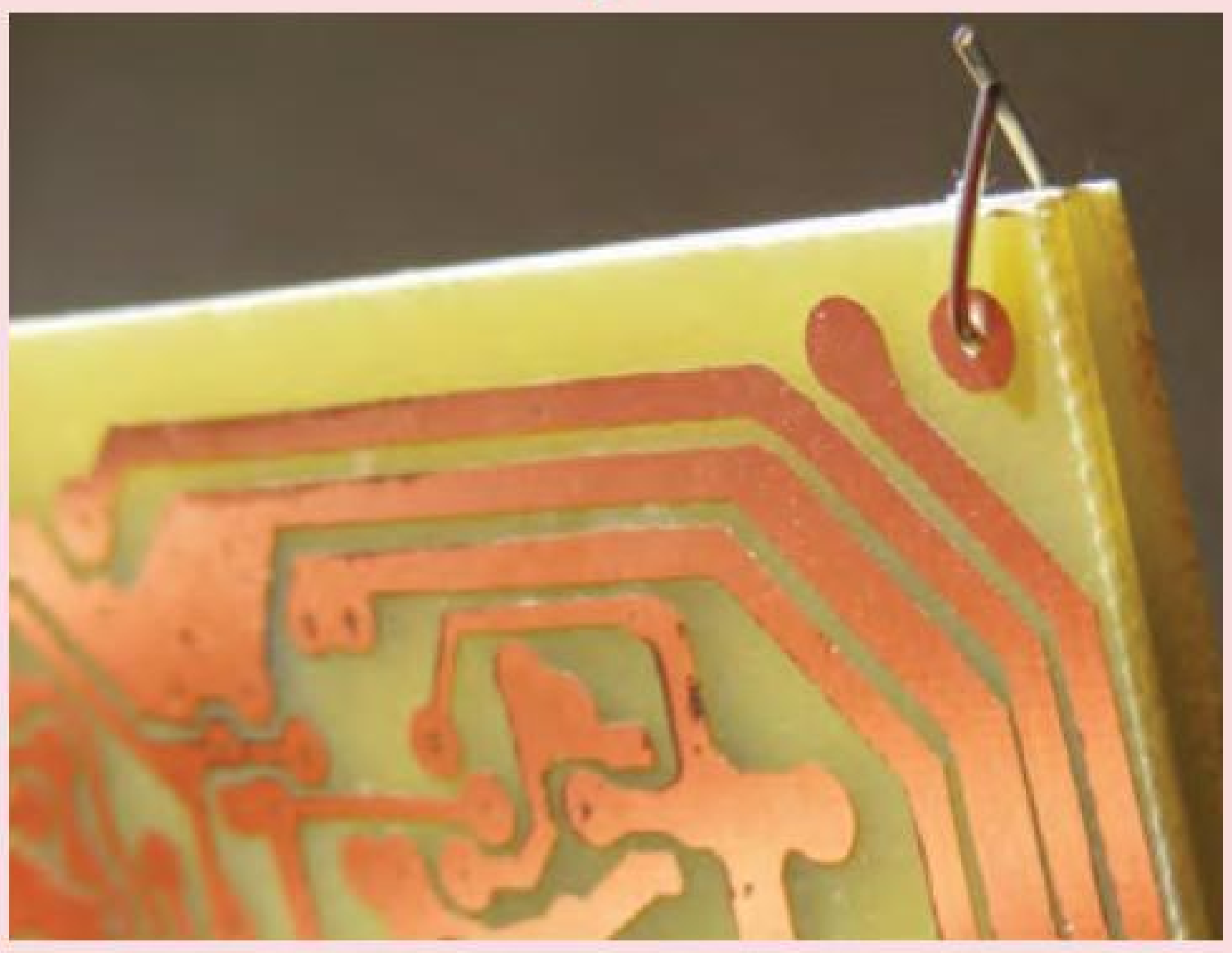


Fig.25g. Two boards aligned with each other using wire in pre-drilled corner holes means you can drill two sets of holes at the same time.

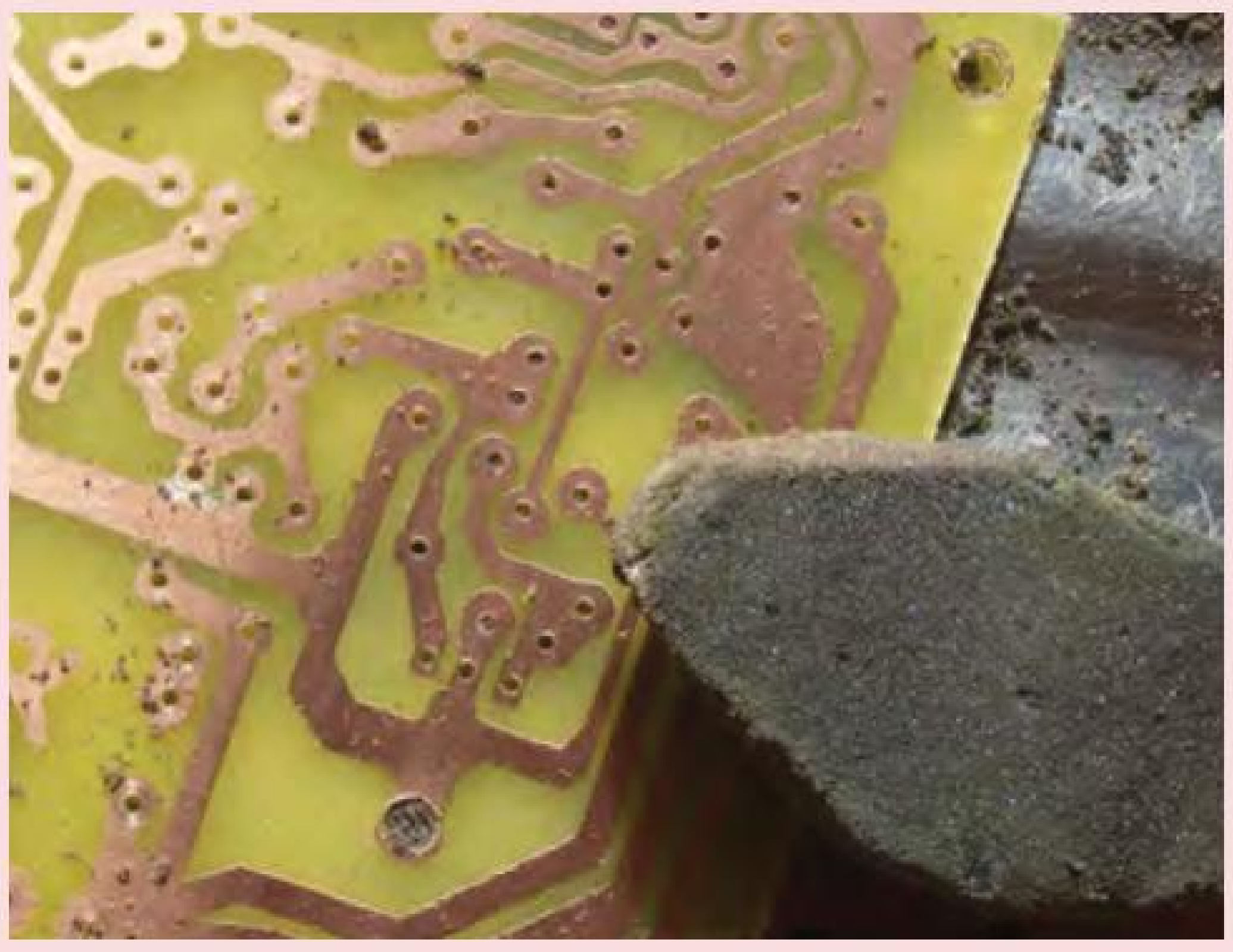


Fig.25h. Cleaning the board with a glass-filled rubber.

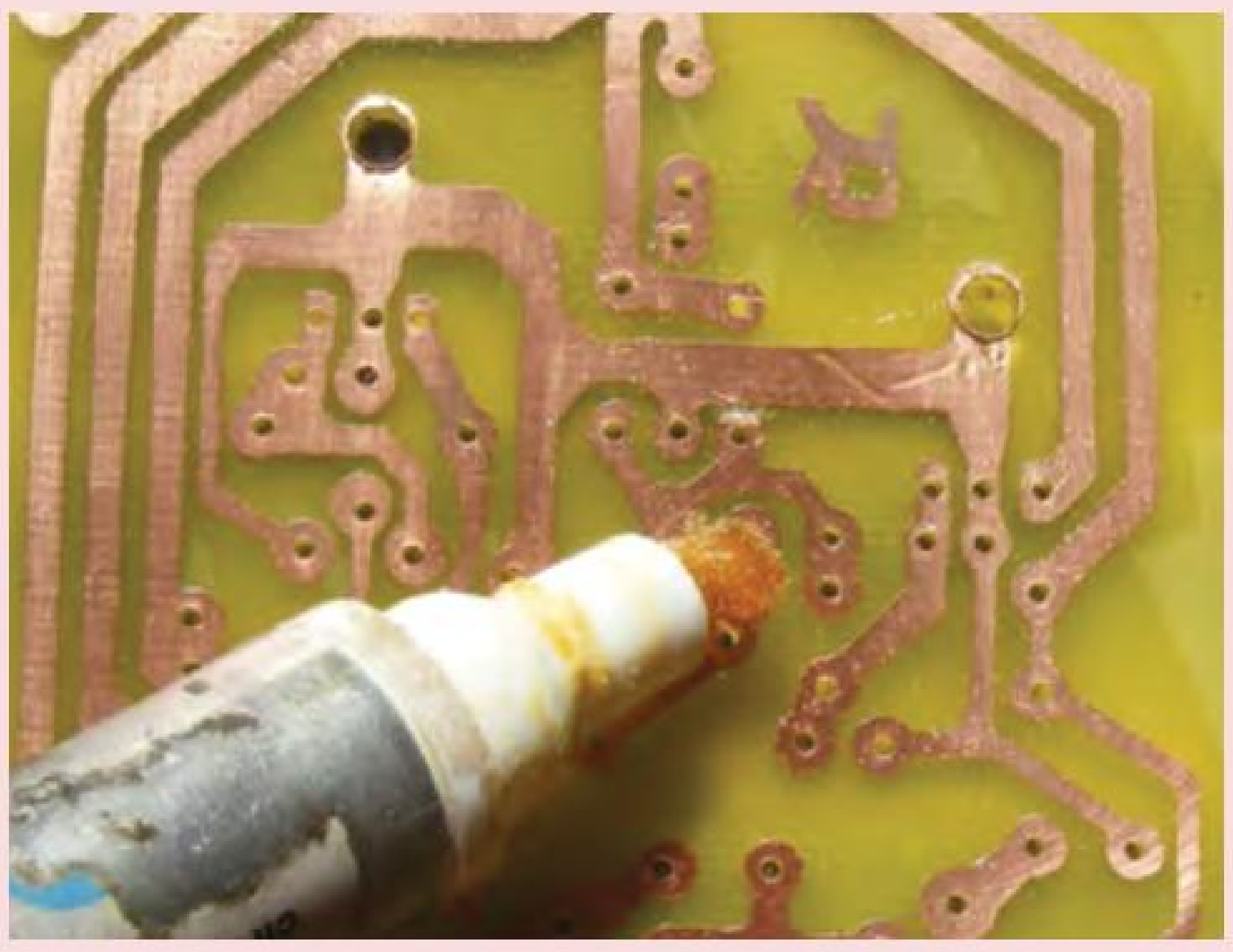


Fig.25i. Using a flux pen to coat the board after etching to prevent corrosion and as an aid to soldering.

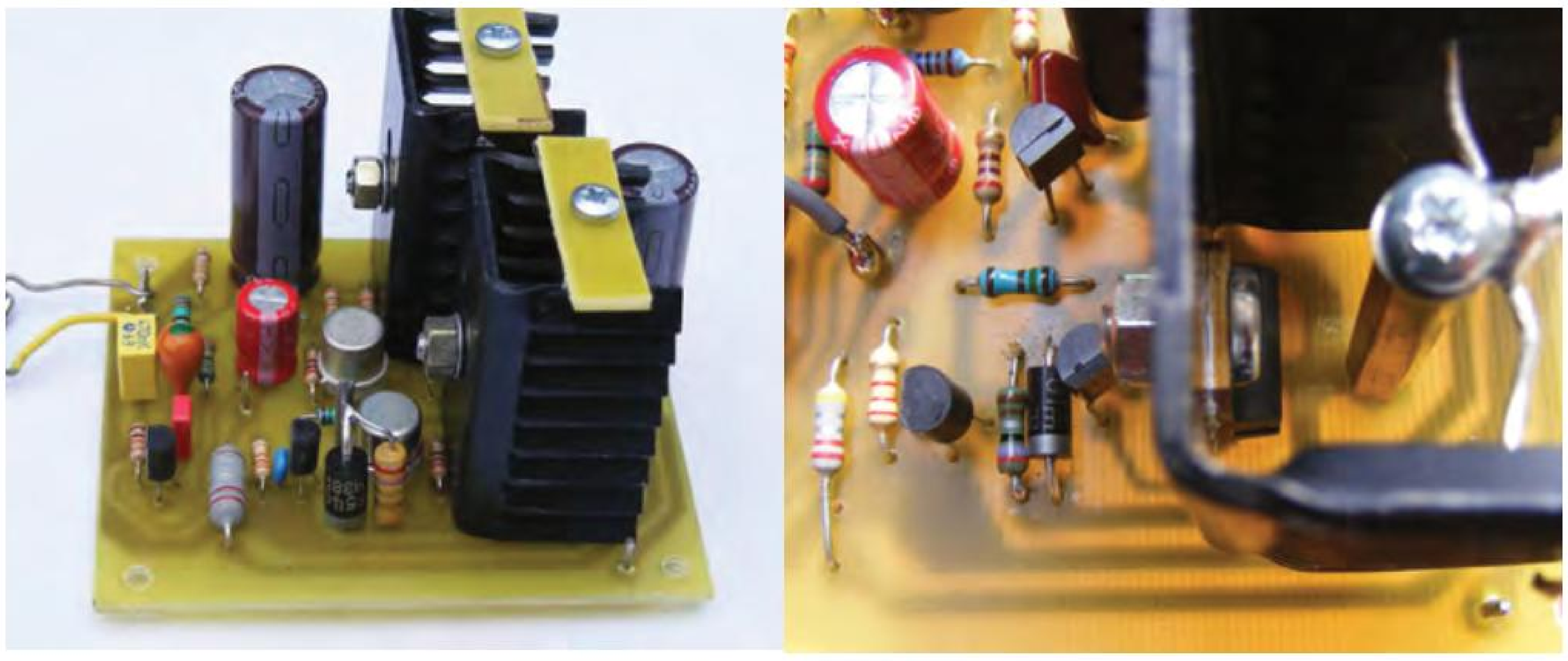


Fig.27. Different orientation of output and driver transistors in the higher power amplifier.

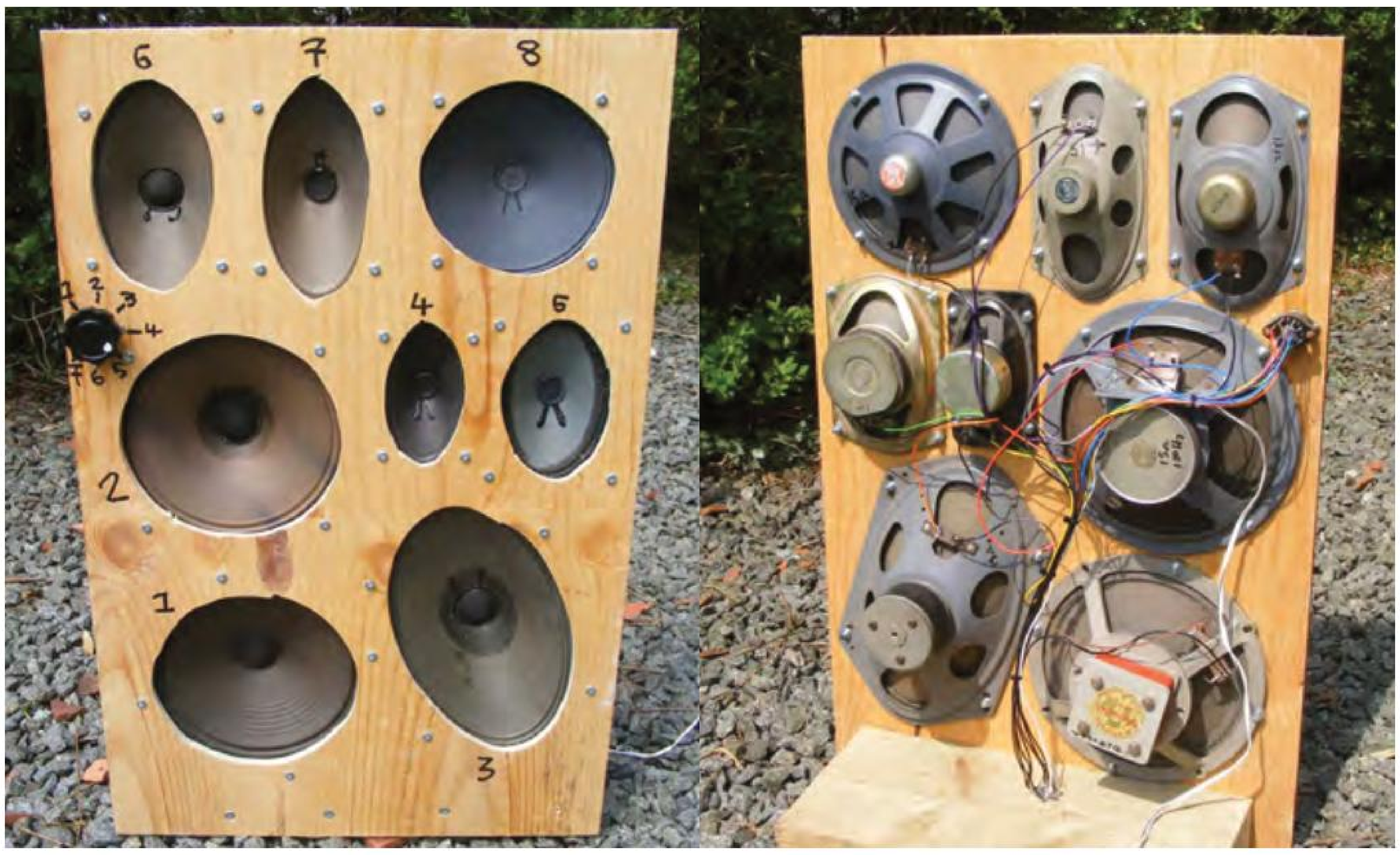
Check your stock

I built one amp, which clipped prematurely. The cause was a low-gain MJE243G transistor, which produced an h_{fe} reading of 22 at 5mA on my Peak analyser. I tested it with I_C = 40mA, the minimum specified current and it was still below 30. I then checked my stock and found all those from batch F40 were the same. RS Components promptly refunded me and withdrew the stock. I had transistors marked F49 which were fine and matched their PNP complements with a range from 70 to 160. So, the moral of the story is if a circuit doesn't work, don't automatically assume the problem lies with your design or construction. Sometimes components are to blame.

Completely mad!

Recently, I've become so obsessed with cone geometry that I built a switchable array shown in Fig.28. My music technology students love it, as I can let them hear the effects rather than just look at plots.

Fig.28. (Below) Speaker array for teaching purposes. Elliptical, Straight-sided and curved cone profiles are all demonstrated.



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Max's Hot Beans

By Max The Magnificent

It's gaming Jim, but not as we know it

It's strange for me to reflect that when younger readers see the above title, they may not get the play on words relating to science officer Mr Spock's 'It's life Jim, but not as we know it', from the original series of Star Trek (1966-1969). I recently celebrated the 38th anniversary of my 21st birthday (coincidentally, this was also the 29th anniversary of my 30th birthday), and it's amazing to me when I look back and ponder how so many things have changed since those far off days when I was a bright-eyed, bushy-tailed young lad bouncing along through life with a cheery whistle on my lips and a merry song in my heart.

25 years before Y2K

I graduated from high school in the summer of 1975. I remember chatting with my friends about the year 2000, which was still a quarter of a century in the future at that time. Thinking about the end of the 20th century seemed unreal – I don't think we really felt we'd ever get there – so it's extremely weird to think that Y2K is now 16 years behind us and rapidly receding in the rear-view mirror of our lives.

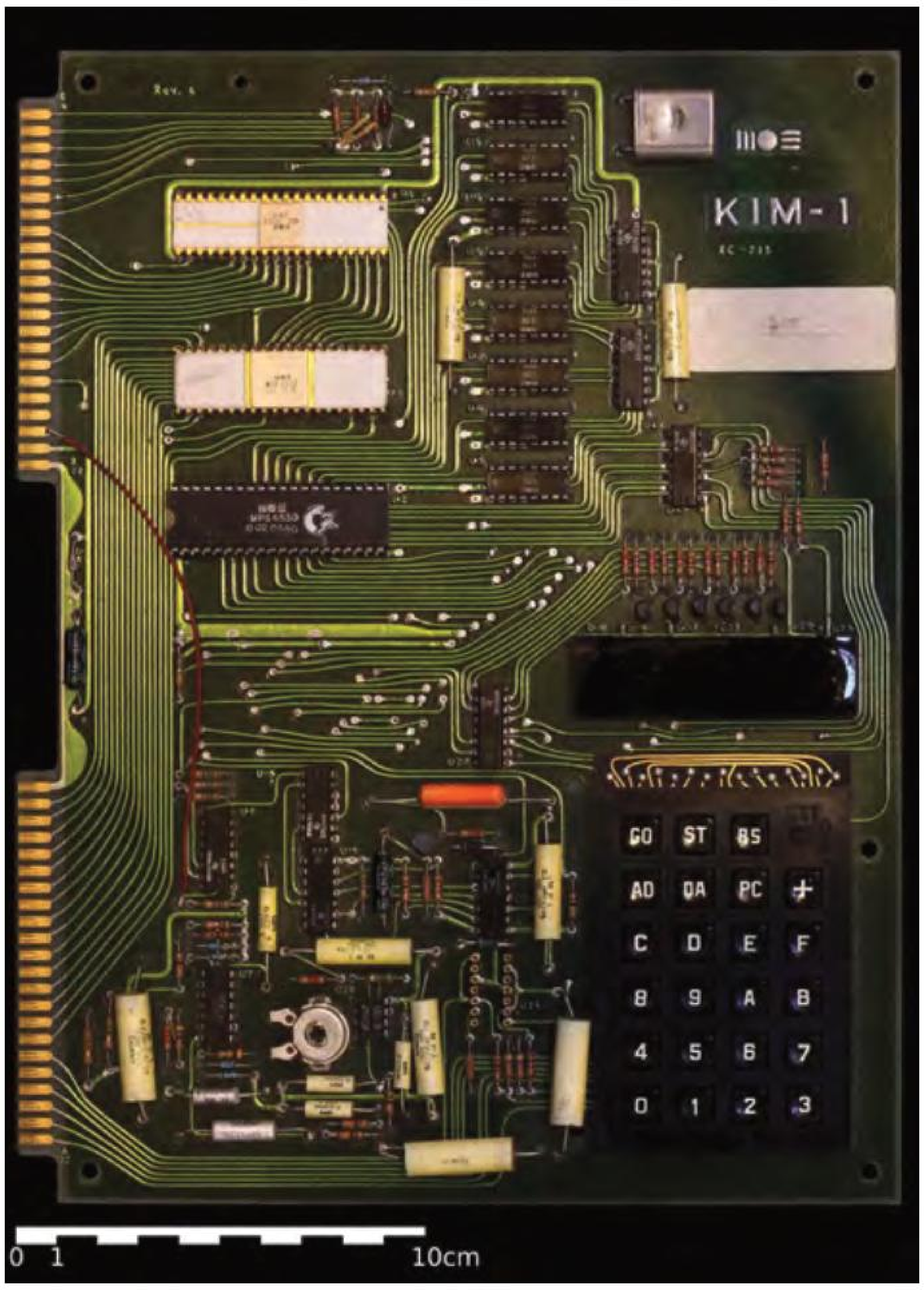

Fig.1. Launched in 1976, the KIM-1 (Keyboard Input Monitor) was a 6502-based single-board computer developed and produced by MOS Technology

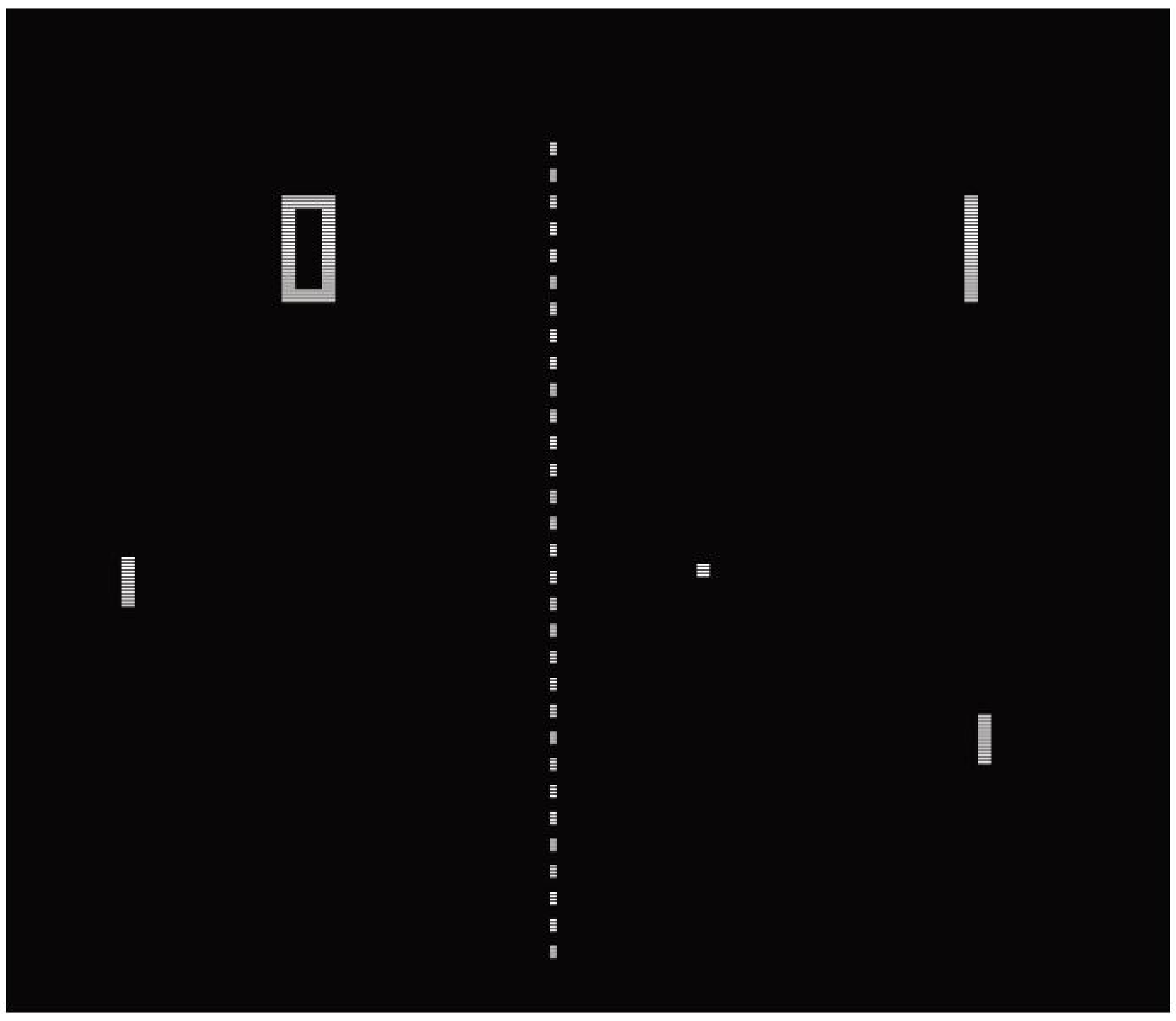

Fig.2. Pong – the ultimate in minimalist games graphics from 1972

While I was at university during the latter half of the 1970s, I used to read *Practical Electronics* magazine (one of the forebears of today's illustrious *EPE*). I remember drooling over an advert for a single-board computer that appeared month after month. I think it might have been a 6502-based KIM-1 (short for Keyboard Input Monitor), with 2KB ROM, 1KB RAM, six 7-segment displays, and a 24-key calculator-type keyboard. I tell you, I wanted that little beauty so bad, but I simply couldn't afford it at that time.

Hardly immersive

Once I started work, I did get to own some simple computers. I don't remember them all, but looking at the bookshelves here in my office I see a variety of 6502, 8080, and Z80 assembly language programming books, along with a couple of 68000-based Atari ST tomes.

When it comes to computer games, the younger folks of today typically have no clue as to just how rudimentary were the early offerings. The first computer game to use a graphical display was a version of noughts and crosses called 'OXO' (also known as 'tic-tac-toe'), which was created in 1952 by Alexander Douglas for the EDSAC computer at the University of Cambridge (**http://bit.ly/298lWX6**). In the case of video, or arcade-style games, possibly the most famous – although it wasn't the first – was Pong, which debuted in 1972 (**http://bit.ly/1JQZDlB**).

Now, don't get me wrong here; even though I'm not much of a computer game player myself, the early games were a lot of fun. However, it has to be acknowledged that the graphics were pixelated and simplistic at best. Over time, of course, computers and their graphics subsystems became more and more powerful, but they were still a long way from being photo-realistic.

Lost in the Myst

I have lots of friends who enjoy the 'shoot-them-up' type of game, but I'm really not all that interested. The first game that truly captured my attention was Myst. This was developed by Cyan and published in 1993, which is 23 years ago as I pen these words (eeek!).

Myst involves you meandering your way around an interactive world, interacting with objects and solving puzzles. The graphics were amazing for that time. The way Myst's creators got around the poor graphics performance offered by the systems of the day was to pre-render very visually tasty scenes; when you clicked on a target location in the current scene, you cross-faded to the new location.

Myst was followed by Riven, which appeared in 1997 (**http://bit.ly/29boSnj**). Although this was only five years later, the graphics in Riven were much more sumptuous. A lot of folks will tell you that playing computer games makes people into antisocial loners, but I know a lot of guys and gals that look back fondly at the time they spent playing Myst and Riven with their family and friends.

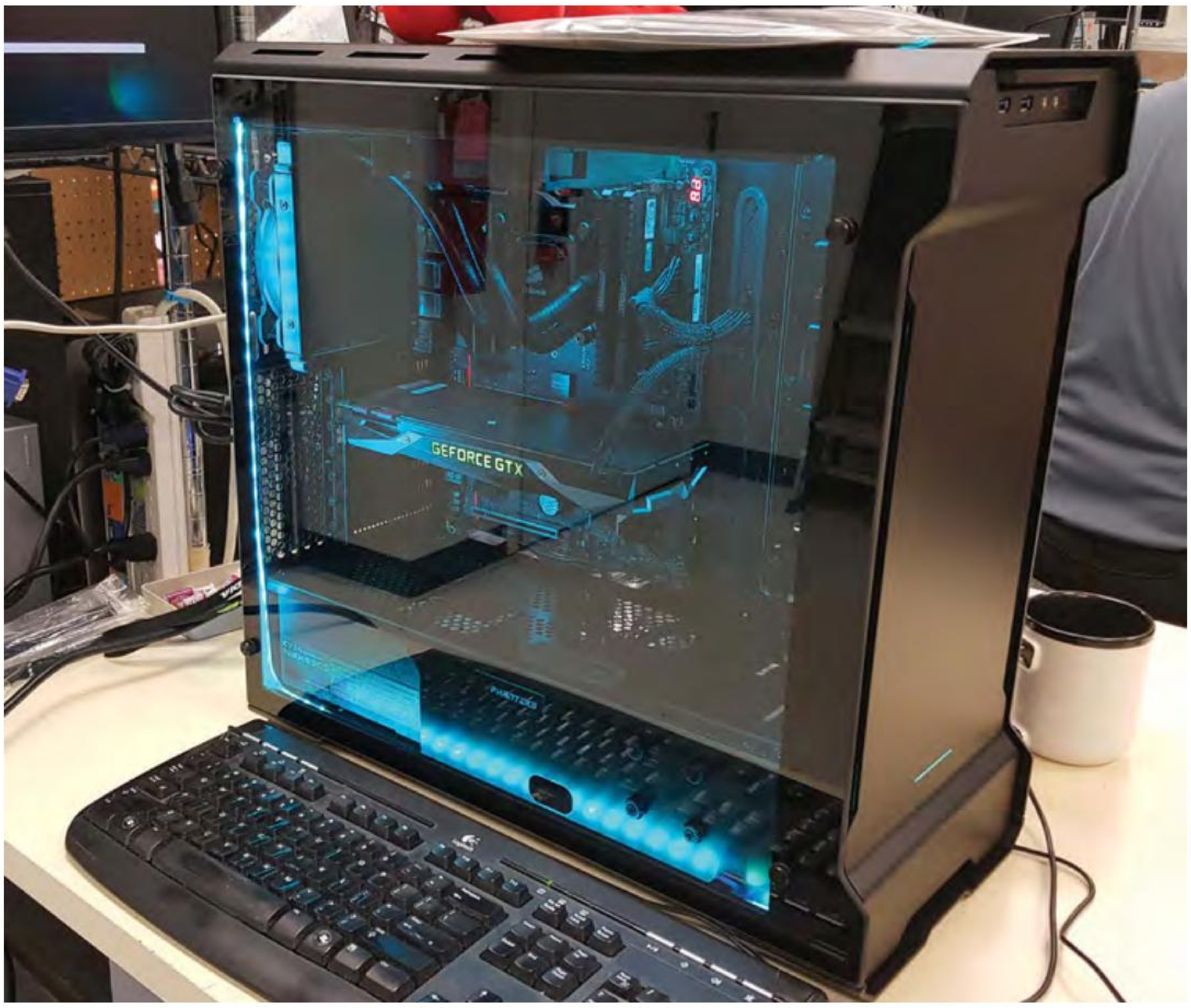

Fig.3. Max's monster virtual reality machine, complete with go-faster blue LEDs

I can't wait to be Obducted!

Fast-forward to 2013, I saw a Kickstarter project for a new Cyan game called Obduction. This was billed as 'The spiritual successor to Myst and Riven'. You have to see the teaser-trailers on YouTube (**http://bit.ly/29ay34o** and **http://bit.ly/29yvO9F**). I immediately pledged to this project, and was delighted when they made their $1,300,000 stretch goal to port the game to the Oculus Rift 3D Virtual Reality headset (**http://ocul.us/1B1JCoL**).

A few months ago, I received an email from Cyan saying that Obduction will be released on 26 July, and that the initial release comes with full Oculus Rift support. Of course, this meant that I needed an Oculus Rift. What can I say? I am a weak man. I couldn't resist. I immediately placed an order, and 'my precious' arrived a week ago, but there was a fly in the soup, as it were...

Great big hairy machines

I feel like an old fool (but where are we going to find one at this time of the day?). I really hadn't given much thought to the sort of computer-graphics-card-combo I was going to need to drive my Oculus Rift. I think I'd vaguely thought that the tower on my desk – boasting a quad-core 3.5GHz Intel Core i7 processor and a graphics card that can drive my three 28-inch monitors – would do the job.

But when I came to look at the 'minimum requirements' on the Oculus Rift website, I realised that I needed something more. Thus it was that I called my chum at GigaParts, Daniel Imsand, where, among other things, they build awesome computer systems (**http://bit.ly/1BGUa7q**).

As it turned out, Daniel had just returned from a VR conference and he said that he had me covered. In a few days' time, GigaParts will be releasing an entire line of VR machines, but I'm an impatient man and I couldn't wait, so Daniel said that he and the lads would build a custom machine just for me.

Daniel called me earlier this morning to say 'It's ready, come on round', so I immediately dropped everything and raced out the door. Let's start with the cabinet, which is formed from 3mm-thick aluminum with tempered glass sides (they threw in two meters of LED strips 'just because'). There's a sixth-generation quad-core hyper-threaded Intel Core i7 processor running at 4GHz with 16GB of RAM, and this is mated with an Nvidia GeForce GTX 1070 graphics subsystem with 8GB of GDDR5 memory. The CPU is water-cooled and... but I don't want to get you too excited (sit down, take deep breaths, and the dizzy feeling will pass).

OMG!

We quickly installed my Oculus Rift (of course I took it up there with me). All I can say is OMG! Until you've tried this, you simply cannot imagine the quality of the immersive experience offered by this setup. The closest thing I can equate it to is visiting a Holodeck on the Star Ship Enterprise. I actually had a whole raft of things planned for this coming weekend, but all of that is out of the door because I hear the siren song of virtual reality calling and I cannot resist. Until next time, have a good one!

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

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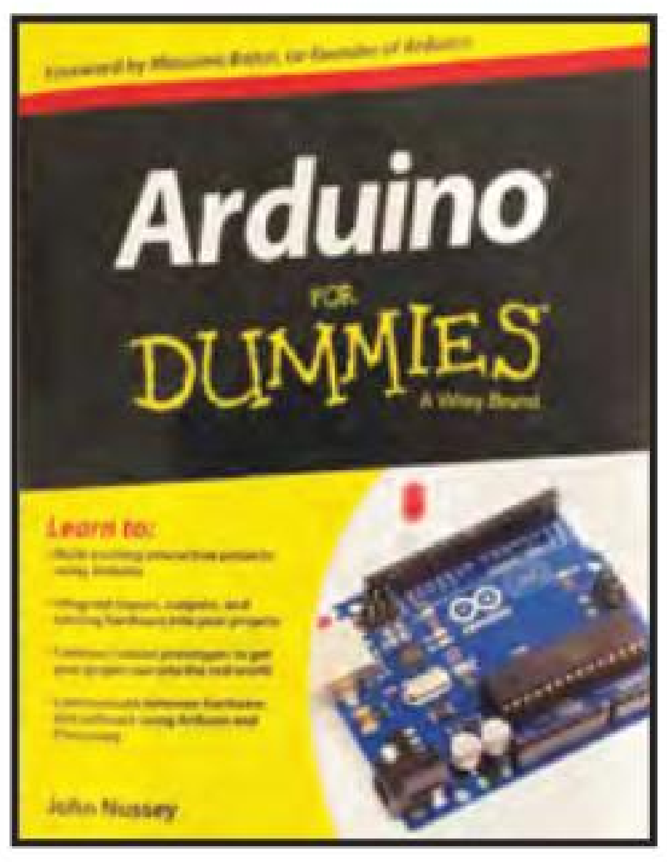

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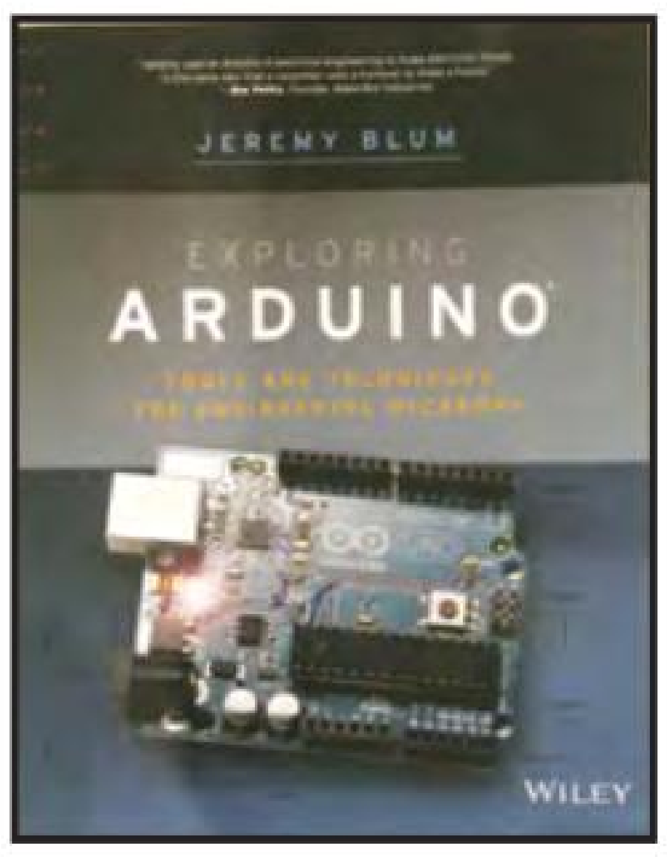

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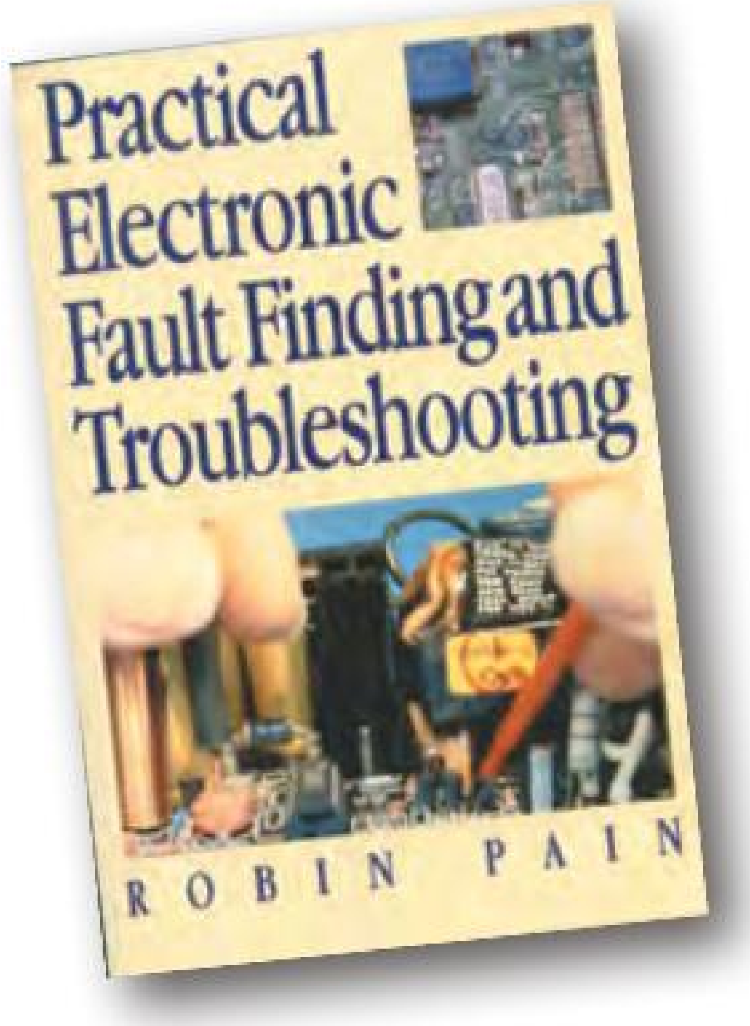

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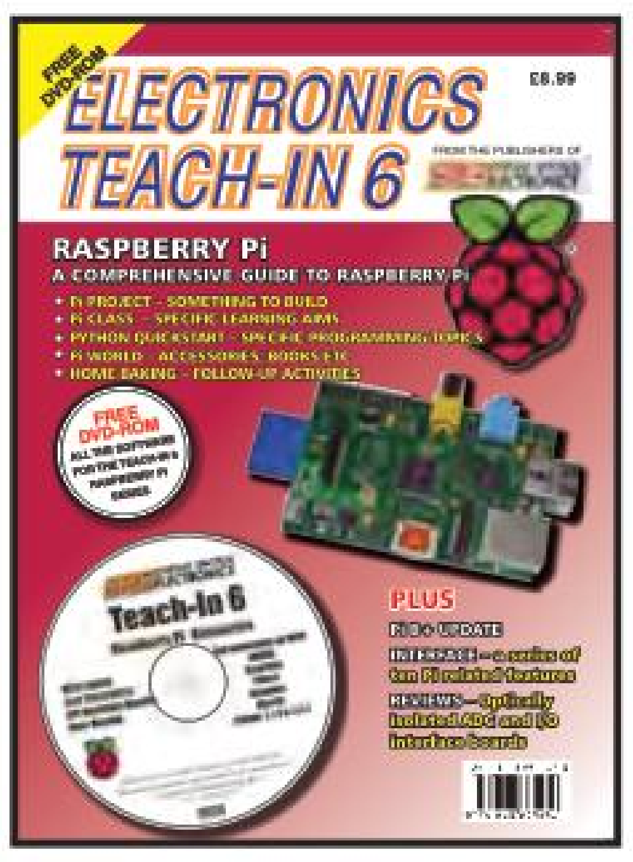

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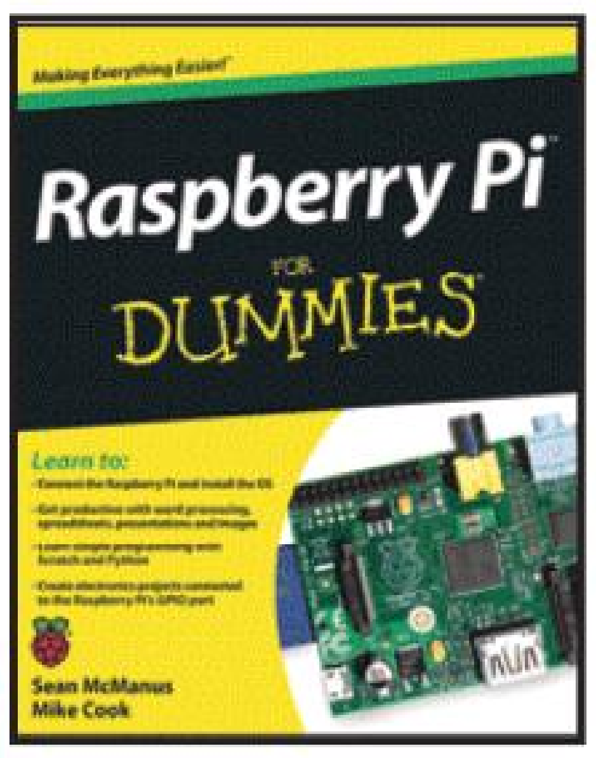

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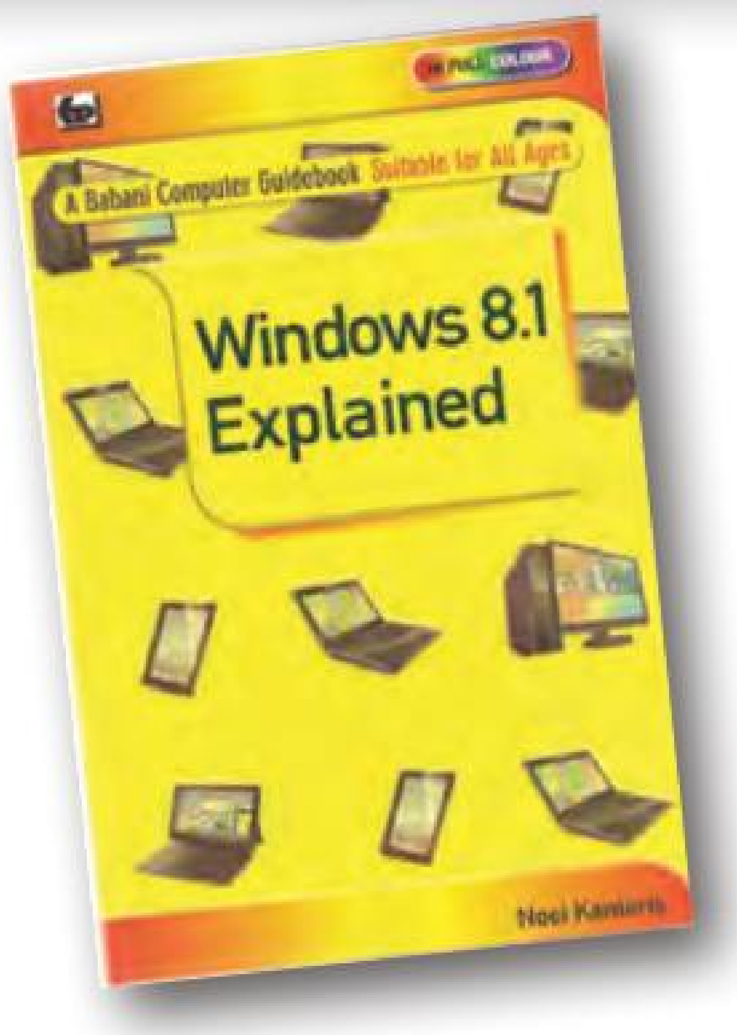

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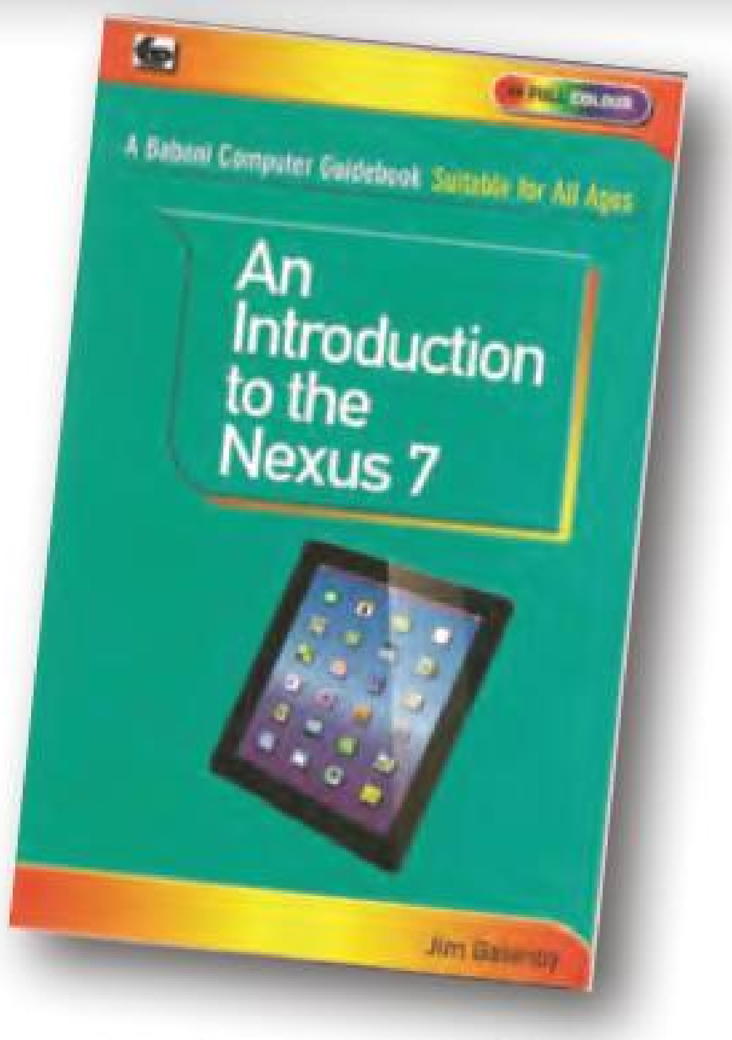
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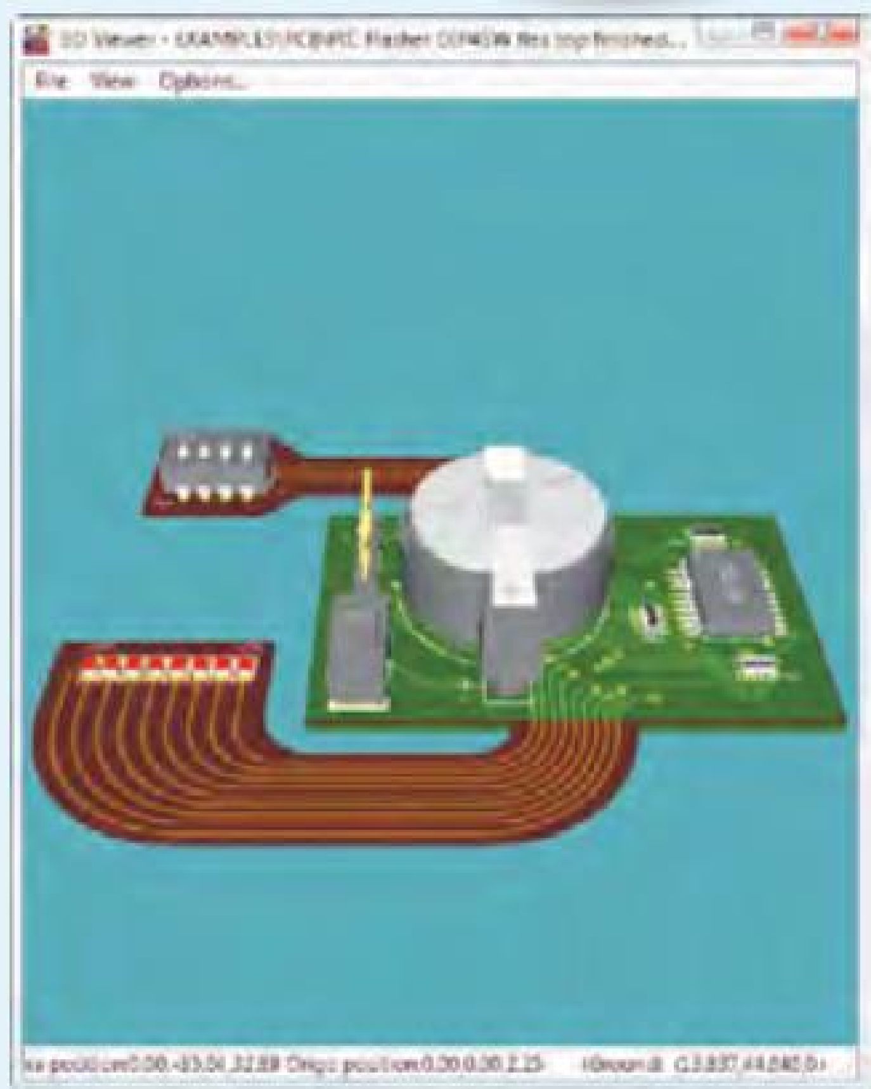

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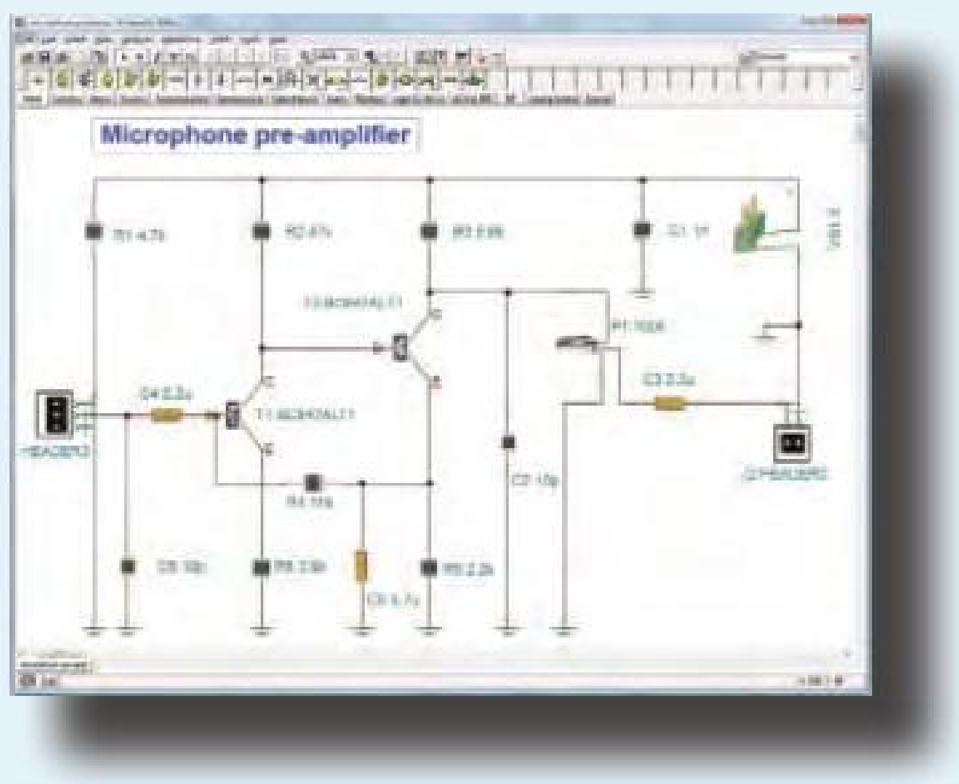

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The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

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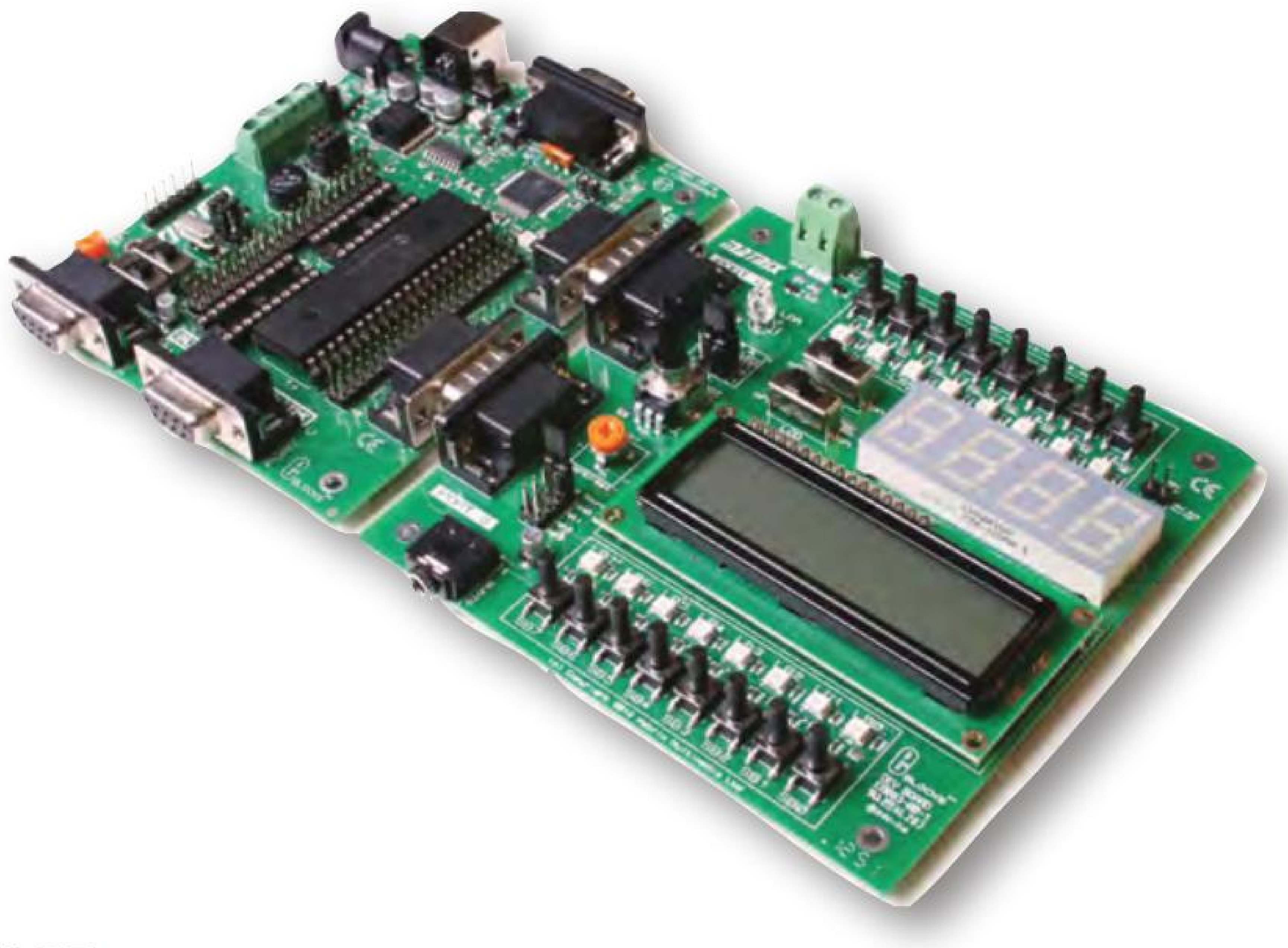

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(Formerly PICtutor)

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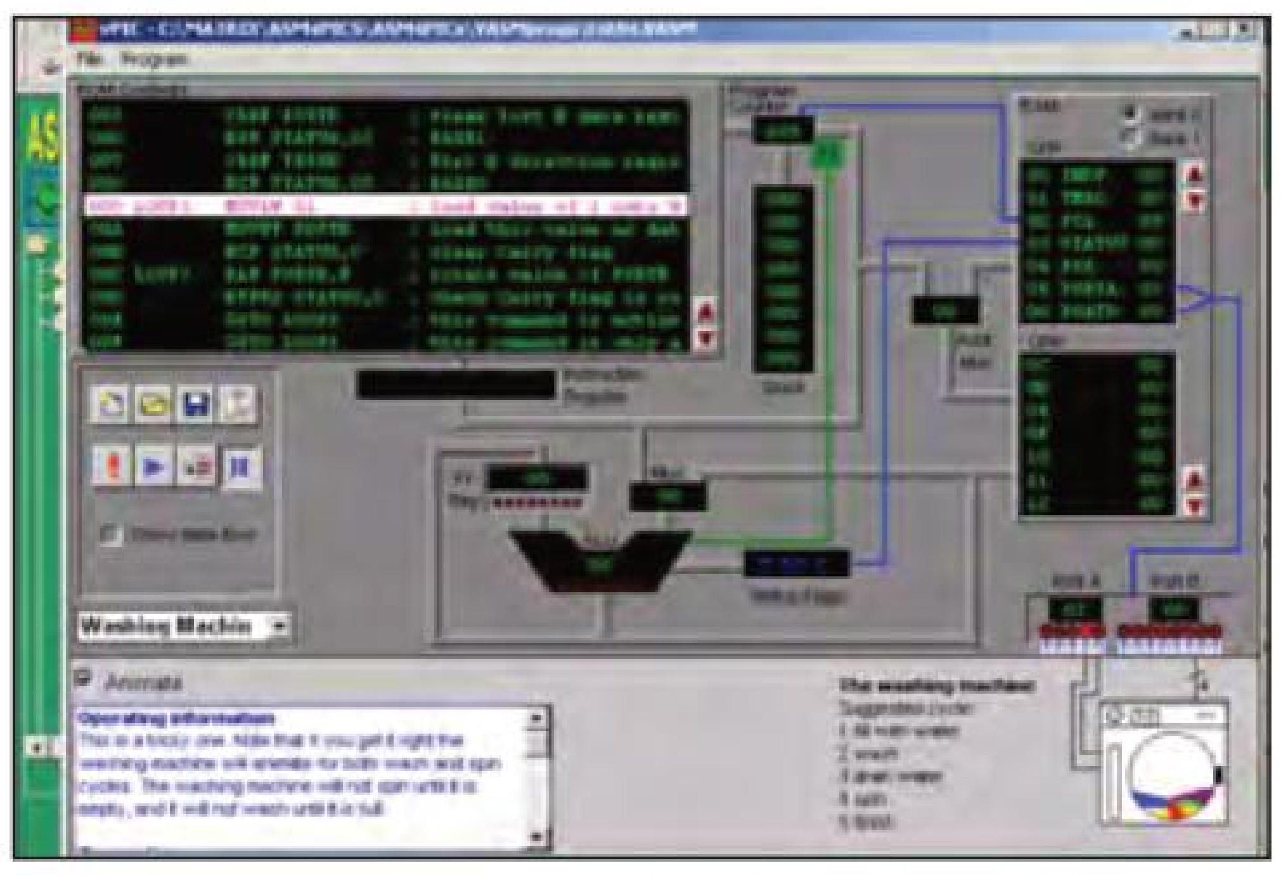

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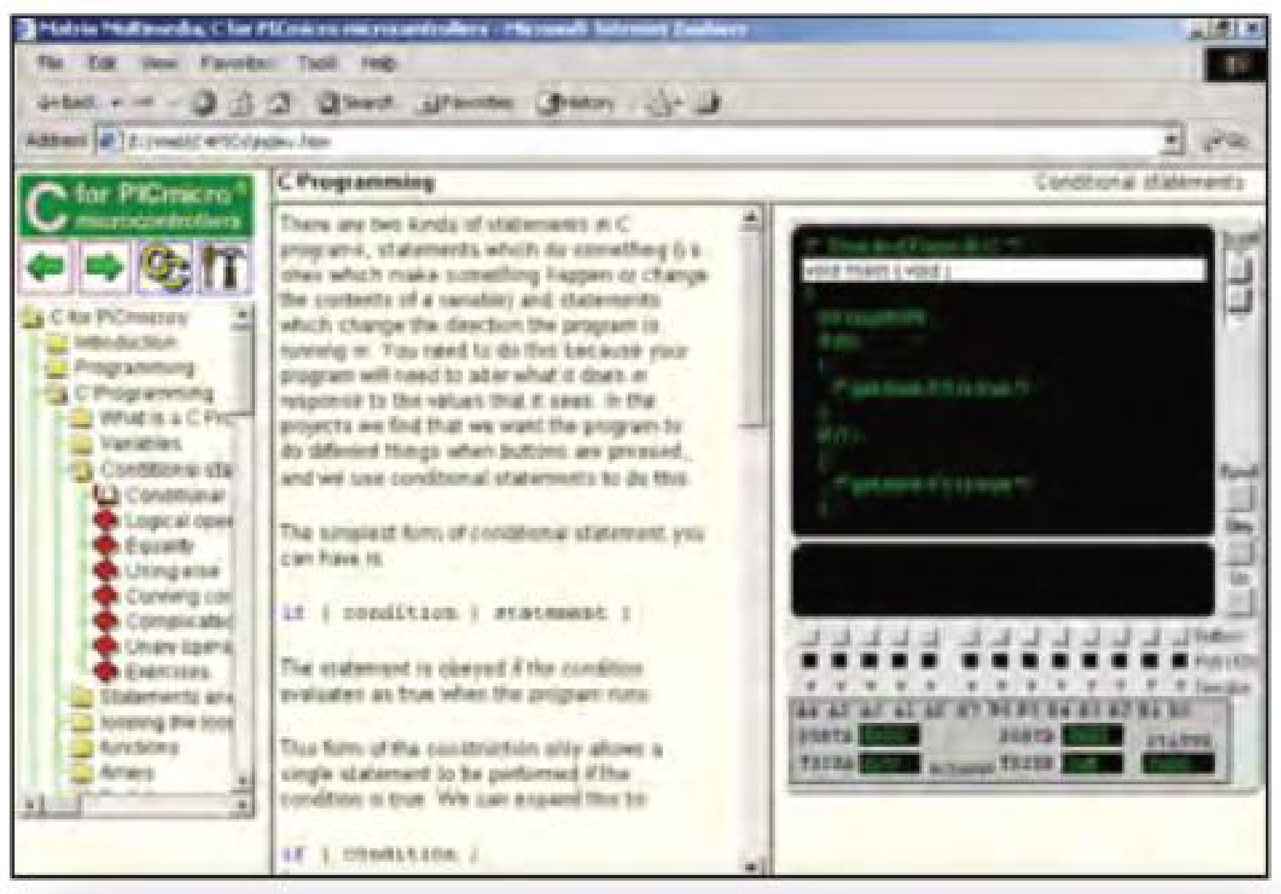

Minimum system requirements for these items: Pentium PC running, 2000, ME, XP; CD-ROM drive; 64MB RAM; 10MB hard disk space.
Flowcode will run on XP or later operating systems

FLOWCODE FOR PICmicro V6

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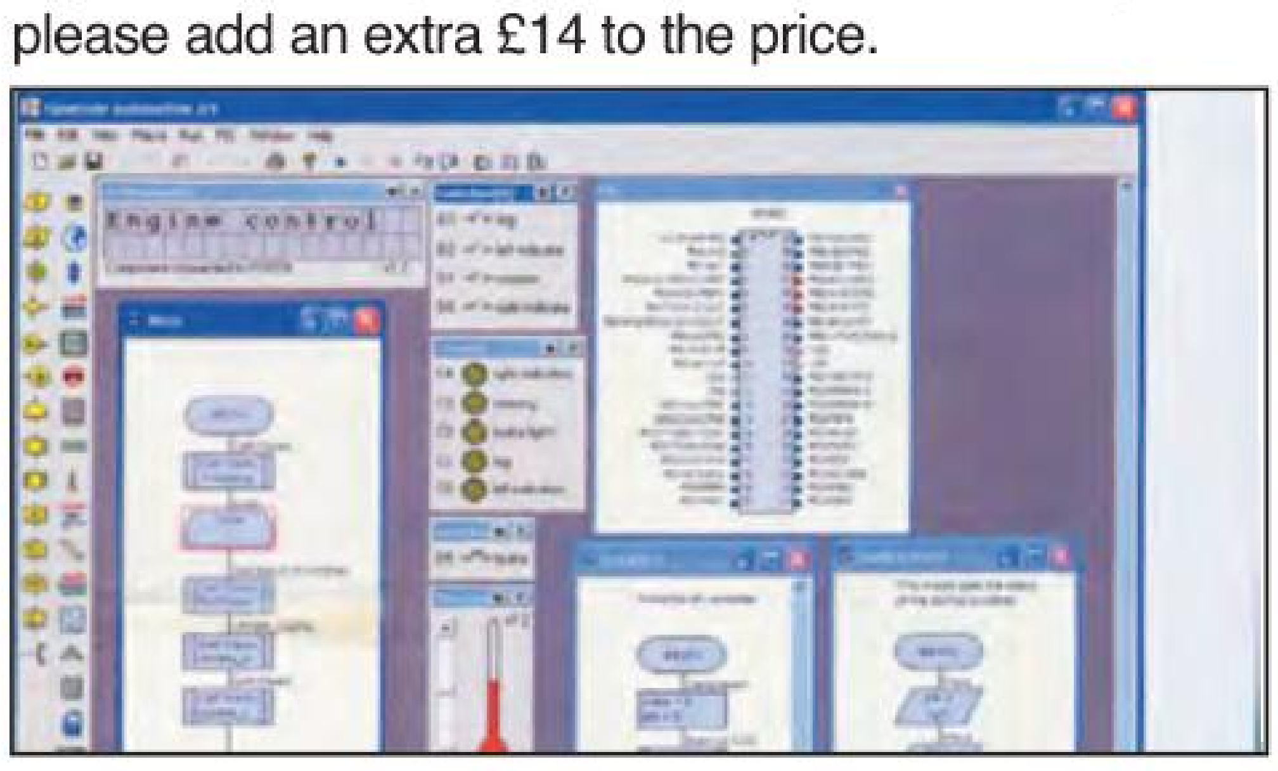
Please note: Due to popular demand, Flowcode PICmicro, AVR, DSPIC, PIC24 & ARM V6 are now available as a download. Please include your email address and a username (of your choice) on your order. A unique download code will then be emailed to you. If you require the CDROM as a back-up then please add an extra £14 to the price.



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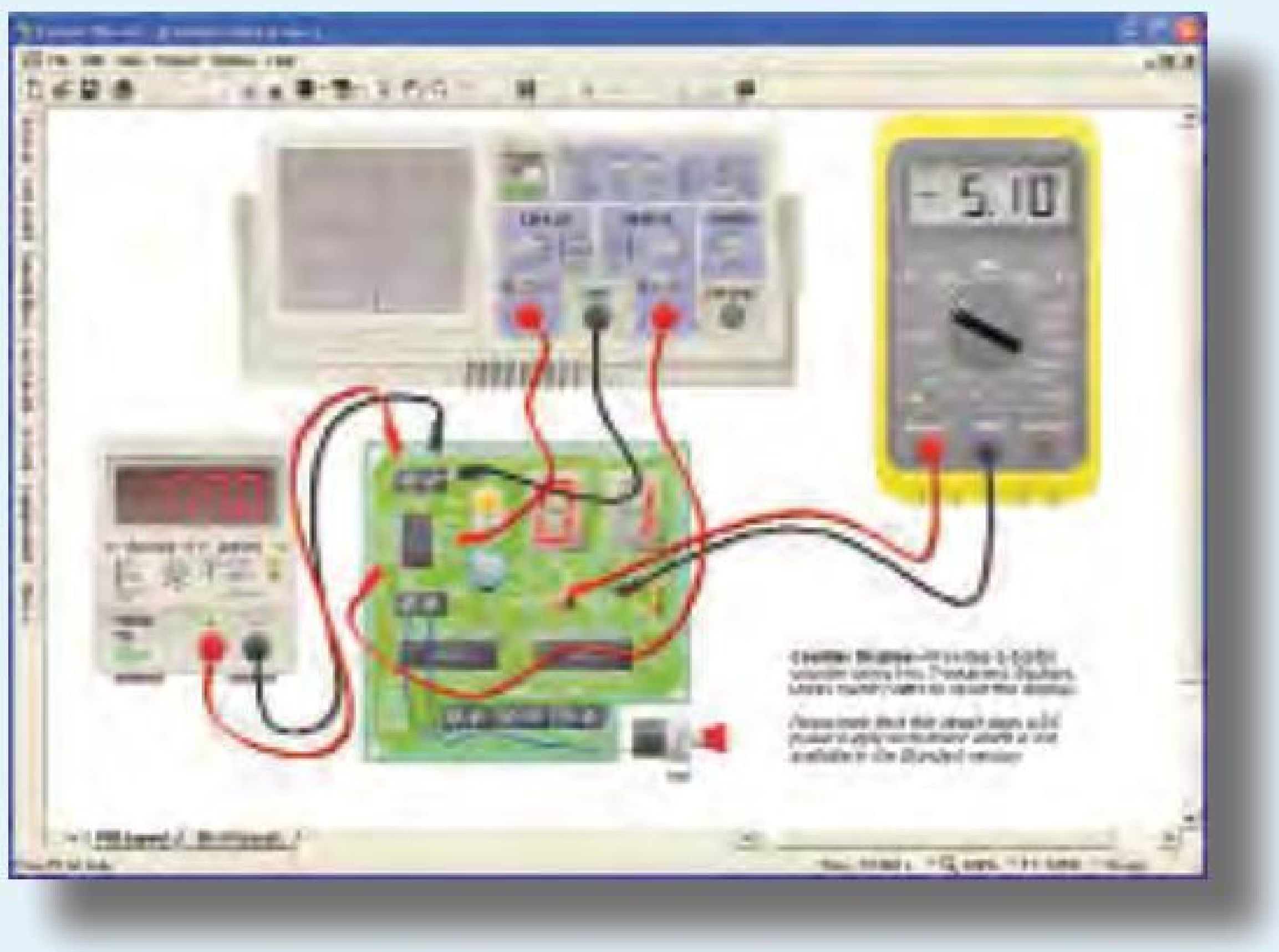

This software can be used with the *Jump Start* and *Teach-In 2011* series (and the *Teach-In 4* book).

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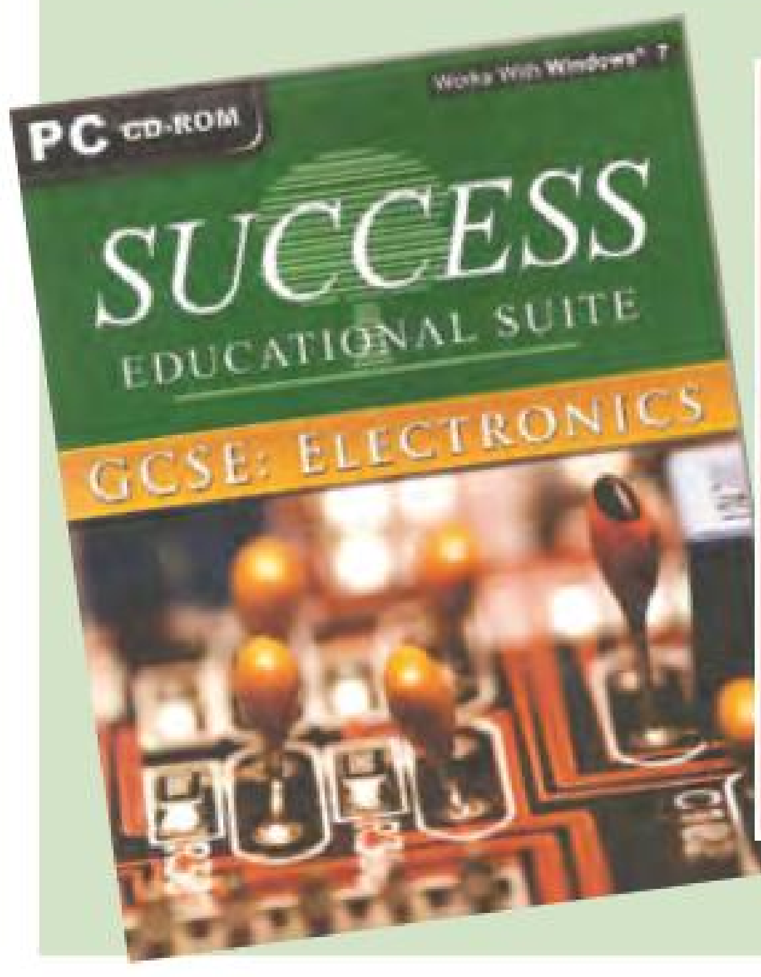

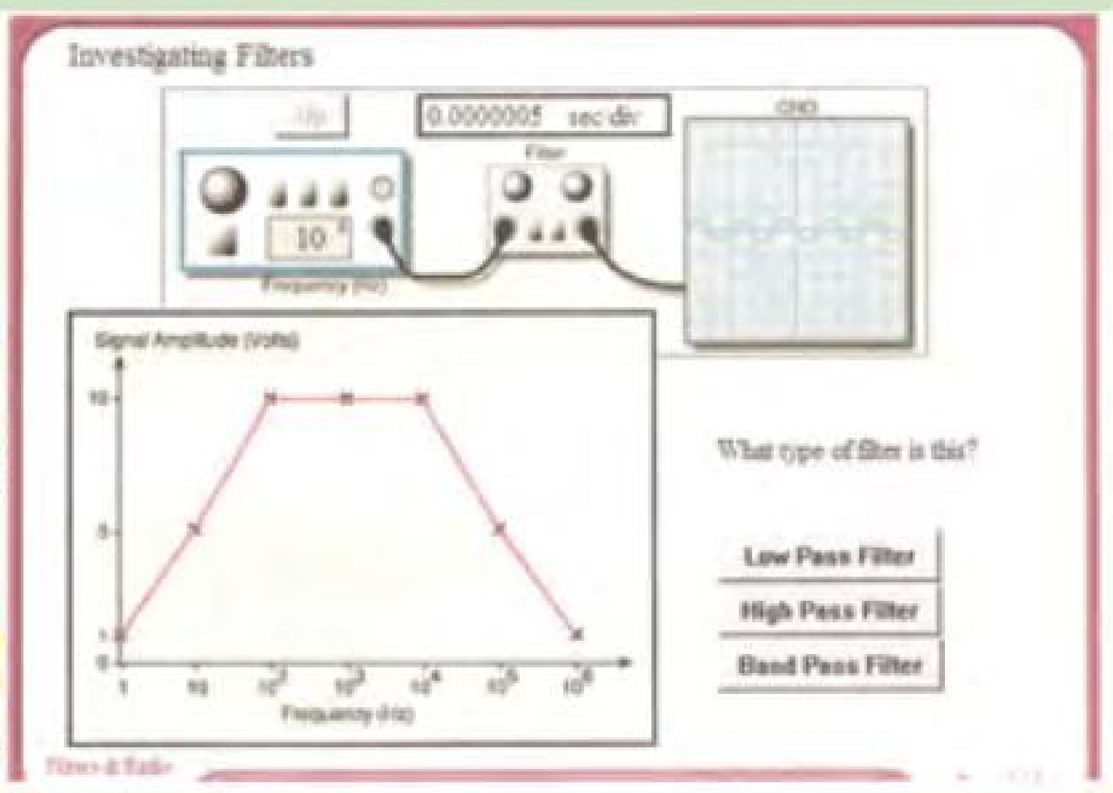

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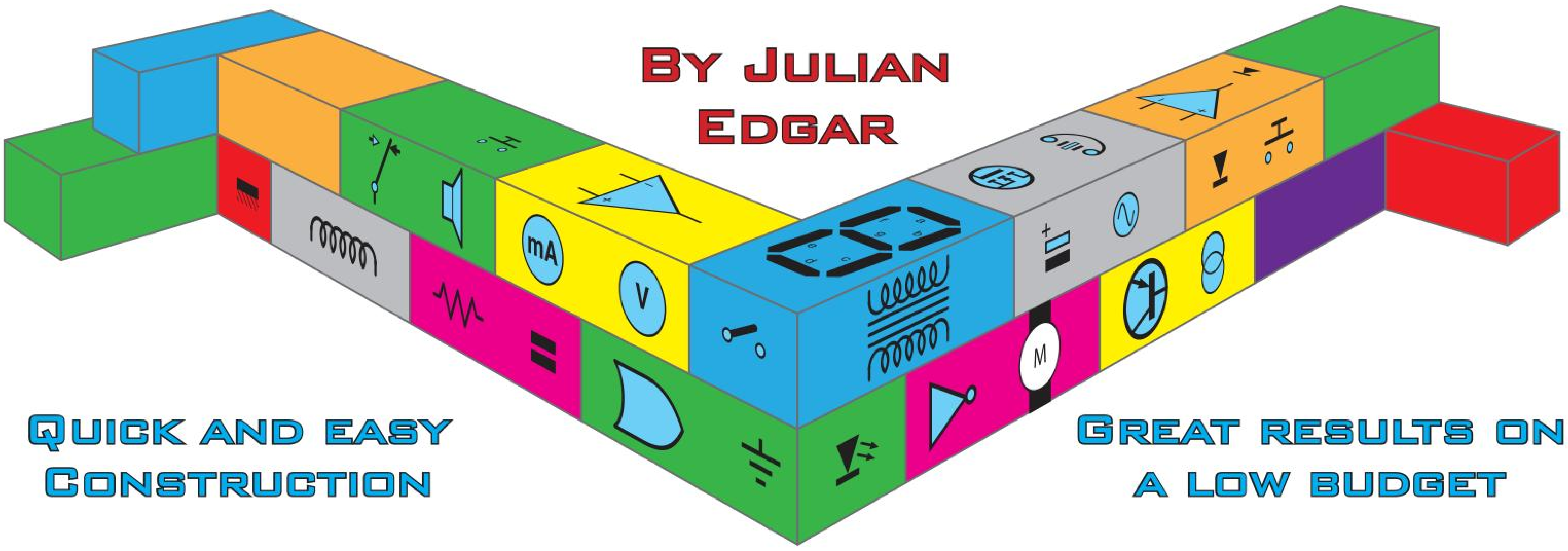
Electronic Building Blocks



By Julian Edgar

Quick and easy construction

Great results on a low budget

LED Battery Monitor

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! These projects range from around £15 to under a fiver... bargains!

Smart LED

We have to say that we're impressed – here's one very smart LED. It's a really smart gadget that does exactly what its UK manufacturer says it will do.

So what is it then? Well, at first appearance it looks just like a 10mm LED mounted in a bezel. But then when you look closer, you'll see a tiny pushbutton – and if you pull the assembly from the bezel, you'll also see a programmable chip and a few other components.

In fact, what we have here is a 6V, 12V and 24V battery-monitoring LED that is user-programmable to run one of six different in-built maps. The single LED can show green, red, yellow (a yellow that actually looks more orange) and white (off). The LED can also flash at different rates. The voltage is monitored as a rolling average over two seconds, is claimed to be accurate to one per cent, and will operate over the range of 3.8V to 30V. In short, it's battery monitoring like you've never seen before!

Wiring is as simple as you can get – red to positive and black to negative. That's it. Here we'll describe the monitor as working with a 12V battery, for example in a car.

The maps

So what are the different in-built battery monitoring maps that are available? There is one for pretty well every use you can think of. Here are the different maps:

Map 1: Battery voltage monitor

This is the factory default voltage indicator mode. Low distraction, minimum of colour changes in normal operation, suitable for vehicle use, such as motorcycles, cars, boats and campers. By flashing and using different colours, it shows eight different voltage ranges from +10.5V to +15V.

Map 2: Vehicle charge indicator

This map illuminates the LED green when under charging conditions – ie, when the vehicle alternator is working. Yellow and red will show if the battery is discharging. This mode monitors seven different voltage ranges from +10.5V to +15V.

Map 3: Vehicle monitor (with fake alarm)

This is great for motorcycles, and vehicles stored long term. When riding/driving and charging, the LED is steady green. 30 seconds after charging stops (ie, the vehicle is parked), the unit will enter low-current mode to show battery status while the vehicle is in storage. The LED will blink green, yellow or red to show the stored-state battery condition. An added benefit is that LED blinking looks like a vehicle alarm. This mode has only a very small current draw (0.5mA) from the battery.

Map 4: Charge indicator (stealth mode)

This is similar to mode (2) but the LED is not illuminated under normal charging conditions. That is, the LED is blank in normal operation. Yellow and red illuminations signal charging faults or a discharging battery.

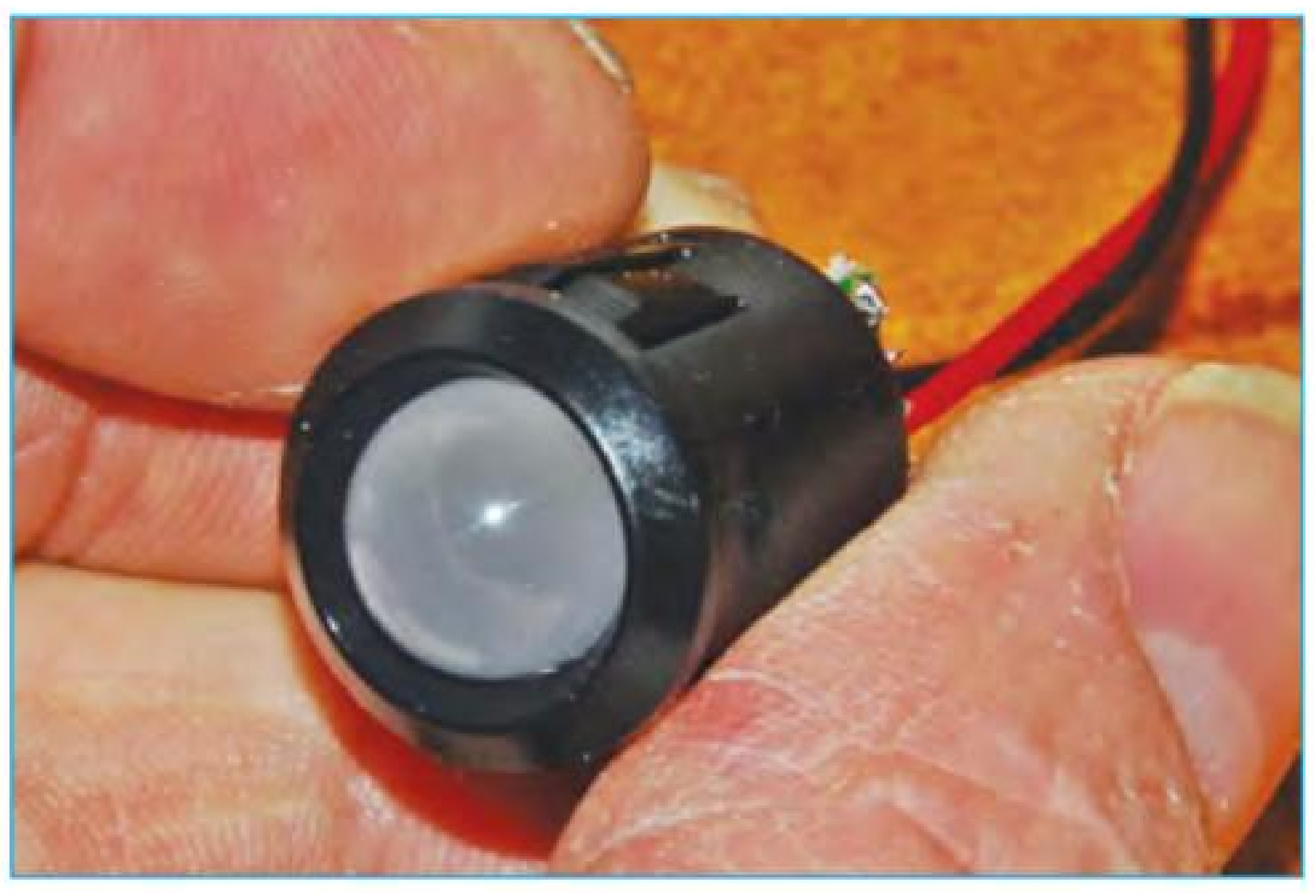


Fig.1. At a glance, the battery monitor just appears to be a 10mm white LED. However, its functionality is much greater than it first appears.

Map 5: High-res 10-step voltage monitor

This mode is a high-resolution mode where maximum resolution is important and colour changes and flashing are not distracting. This mode monitors 10 different voltage ranges from +10.5V to +15V.

Map 6: Minimal monitor

This mode uses a simple low current (less than 0.5mA) for three-colour battery status monitoring. A short flash every two seconds indicates current state, with five different voltage ranges from +10.5V to +15V.

Different voltages

The tricks of the device don't end with the different maps. As mentioned, you can also configure the LED to work on battery voltages of 6V, 12V or 24 volts.

Using it

So is it all good news? Well, we initially found the instructions rather hard to understand – especially in the area of mode set-up. Let's take a look at this aspect.

As delivered, the LED is set to Mode 1. To move to the next mode (ie, in this case Mode 2) you do the following:

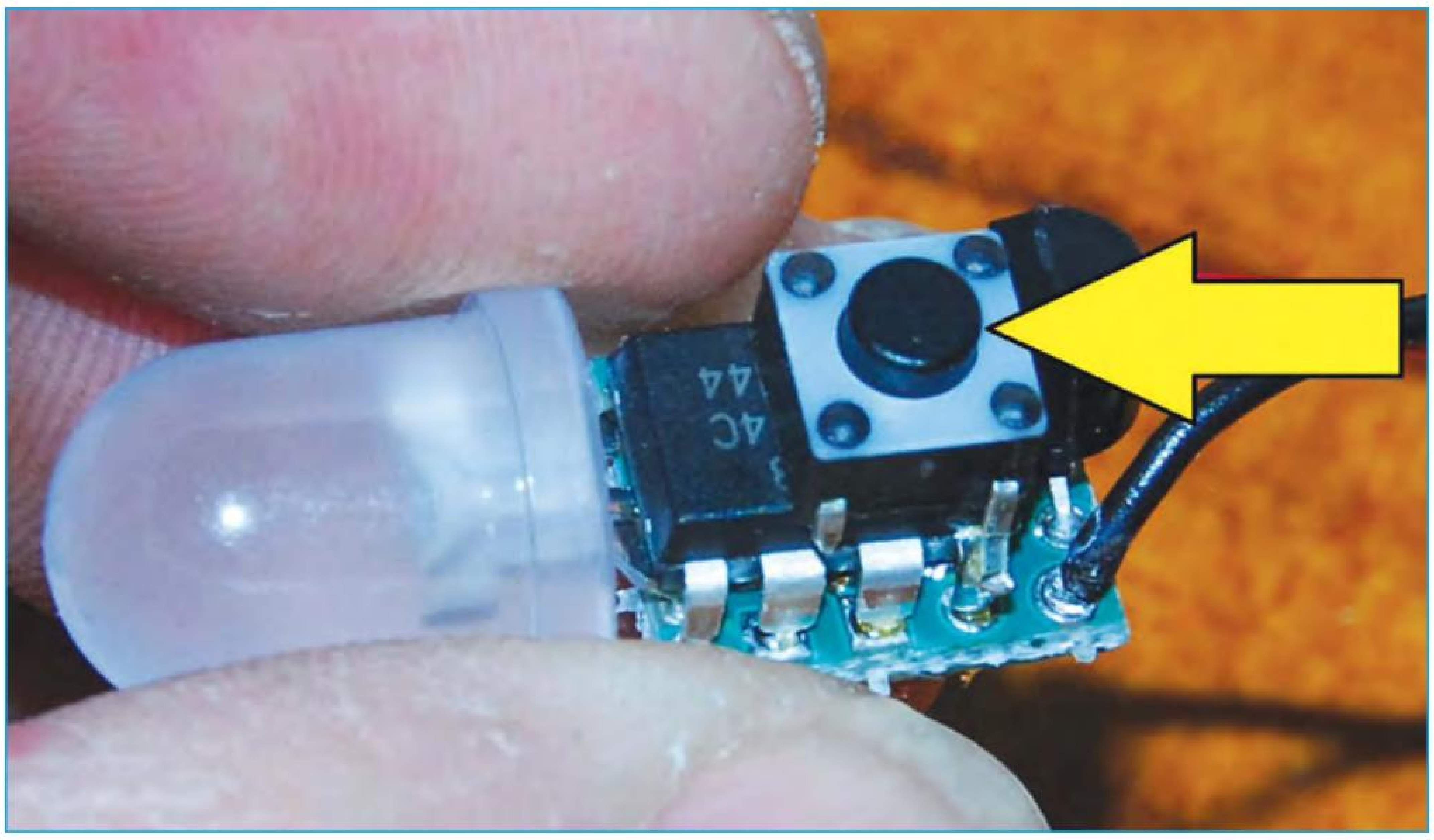
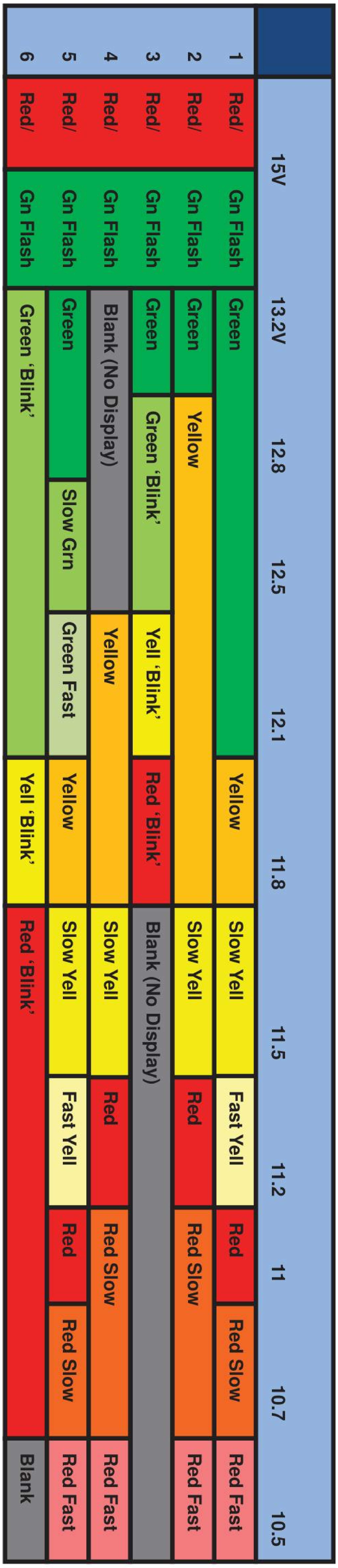


Fig.2. Pulling the LED from the bezel reveals an attached circuit board and pushbutton. Programming of the LED's functions is achieved by operating the pushbutton.



	15V	13.2V	12.8	12.5	12.1	11.8	11.5	11.2	11	10.7	10.5
1	Red/	Gn Flash	Green			Yellow	Slow Yell	Fast Yell	Red	Red Slow	Red Fast
2	Red/	Gn Flash	Green	Yellow			Slow Yell	Red	Red Slow		Red Fast
3	Red/	Gn Flash	Green	Green 'Blink'	Yell 'Blink'	Red 'Blink'	Blank (No Display)				
4	Red/	Gn Flash	Blank (No Display)		Yellow		Slow Yell	Red	Red Slow		Red Fast
5	Red/	Gn Flash	Green	Slow Grn	Green Fast	Yellow	Slow Yell	Fast Yell	Red	Red Slow	Red Fast
6	Red/	Gn Flash	Green 'Blink'			Yell 'Blink'	Red 'Blink'				Blank

Fig.3. (right) This colour chart shows the range of LED behaviours that can be programmed. There are six different modes available.

1. Power-up the LED
2. Hold in the pushbutton
3. Wait until the LED flashes green
4. Release the button

Now here is the trickier bit. To confirm what mode you have now set, turn off power and then reconnect it.

In this case you would expect to see three green flashes (indicates the LED is still in its 12V-battery-monitoring setting), a pause, and then green flashes (indicates Map 2).

The maps settings (the second lot of flashes) are as follows:

Map 1 – red flashes
Map 2 – green flashes
Map 3 – yellow flashes
Map 4 – red and then green flashes
Map 5 – yellow and then red flashes
Map 6 – yellow and then red flashes

(…and do remember we said that yellow looks more like orange.)

Once you've sorted this aspect out, changing the voltage to 24V or 6V monitoring is straightforward. The procedure is:

1. Power-up the LED
2. Hold in the pushbutton
3. Wait until the LED flashes green, then red
4. Release the button

The voltage mode will switch to the next, so 12V to 24V to 6V to 12V – and so on. Then examine the initial flashes after switch-on on the basis of the following:

6V – red flashes
12V – green flashes
24V – yellow flashes

Uses

This little unit is ideal for battery monitoring in cars (especially those driven irregularly), motorcycles, and 6V and 12V portable battery-powered equipment – you name it, if it has a 6V, 12V or 24V battery, this programmable monitor will probably suit. It is also ideal for camping and remote-area power supply systems running off battery or solar power.

Cost

The unit costs, at the time of writing, £10.75 including postage. It is made by Gammatronix in the UK and is available via eBay. Search for eBay item 200843083721, or using the text: '6V, 12V, 24V Programmable LED Battery level voltage monitor meter indicator'.

Next month

I call this a *Phone blaster*. It's an amplifier/speaker combo to play music from a mobile phone – battery powered and with good sound, it's great fun to build and use. So don't miss the next super *Electronic Building Block* article!

PCB SERVICE

CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

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For editorial address and phone numbers see page 7

Next Month

Content may be subject to change

Arduino-based USB electrocardiogram

An easy-to-build Arduino project which will let you take your own electrocardiogram (ECG) and display it on a laptop PC. The software lets you read, display, save and print the electrical waveform generated by your heart – or anyone else's. It connects to your laptop via a USB cable, which also powers the circuit.

Compact Hybrid Switchmode 100W Bench Supply – Part 2

In September's issue, we introduced our new 40V switchmode bench supply which can deliver up to 5A and fits into a compact rack-mount case with dual metering. Next month, we describe the operation of the linear regulator circuit, discuss the PCB layout design and start the assembly by installing the parts on the PCB.

5-Element Yagi Antenna

What's your FM reception like? Pretty poor? If so, you need a proper FM antenna, not a bit of wire hanging out the back of your tuner. But they're not easy to buy these days! So why not build your own *5-Element Yagi Antenna* – designed specifically for the FM band.

Teach-In 2016 – Part 9

In next month's *Teach-In 2016, Arduino World* we will look at methods of connecting an Arduino to a local area network (LAN) and to the Internet using an Ethernet shield. *Arduino Workshop* will introduce you to the practical aspects of using an Ethernet connection to send and receive data using a standard router or hub fitted with an Ethernet port. *Coding Quickstart* will introduce UDP and Network Time Protocol. Finally, our *Get Real* project will describe the design and construction of a highly accurate Internet-connected clock.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks, PIC n' Mix* and *Net Work.*

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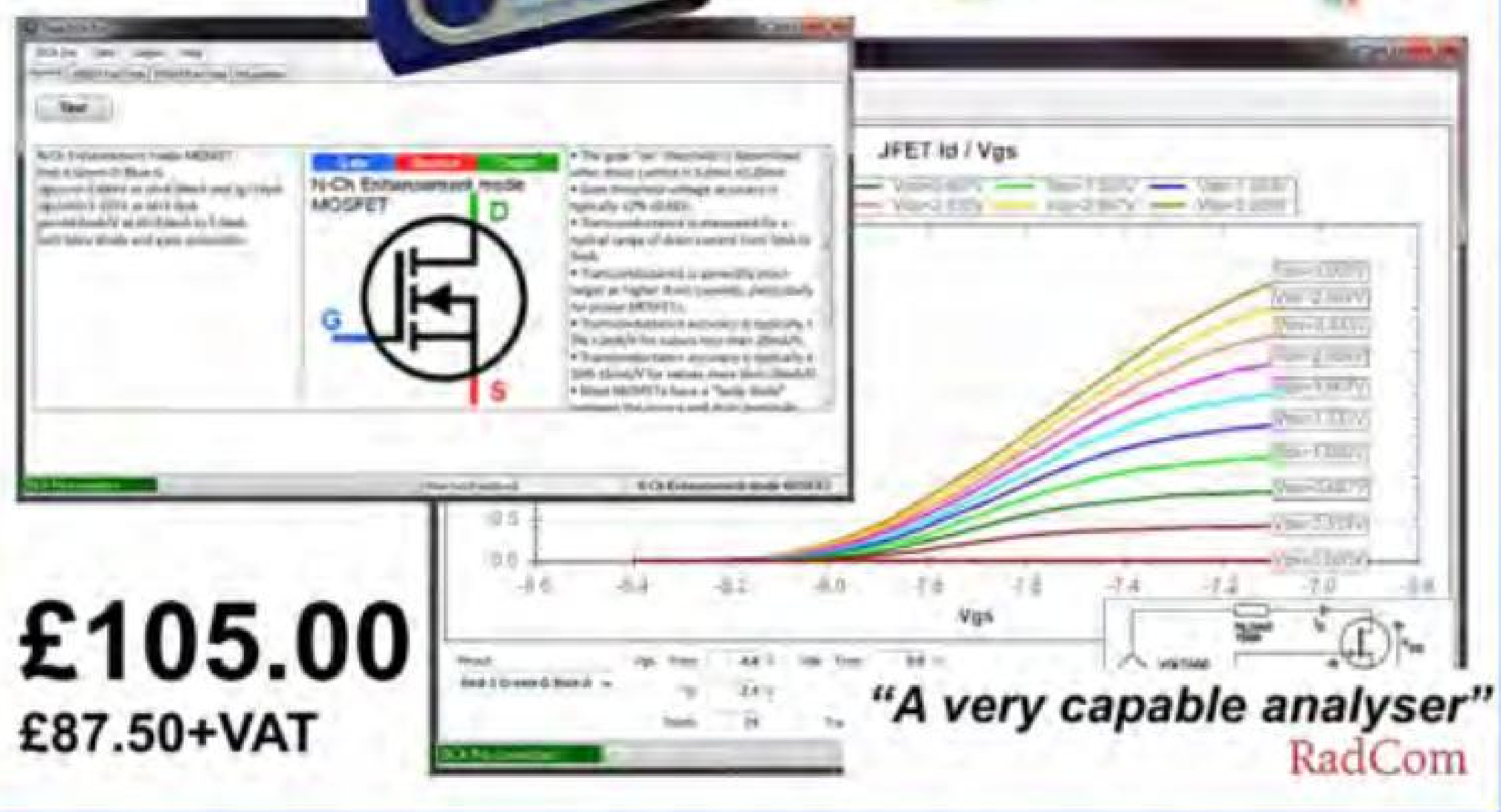
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